

PRELIMINARY

MAX260-268 FILTER DESIGN SOFTWARE User Manual



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MAXIM

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SECTION 1. FEATURES OF PROGRAM "FILTER"

Program PZ	Given the type of filter (Chebyshev, Butterworth, elliptic), cutoff or center frequency, pass-band ripple, Q, attenuation, PZ calculates the center frequencies, Q's, zeros and the number of stages needed.
Program RP	For devices which use resistor programming (MAX255/56), RP calculates the values of the resistors, given the specs of the individual first or second order stages, worked out by PZ.
Program RPCHECK	Given any set of programming resistors, the clock ratio and clock frequency, RPCHECK calculates the actual performance of a stage for all of the modes. This might be used to test the sensitivity to resistor tolerances of a design from RP.
Program MPP	For digitally programmed filters, MPP outputs the proper programming codes and describes the performance of the design when given the filter center frequencies and Q's.
Program FR	When a design of one or more double pole or single pole stages is completed using the above aids for setting up resistors and digital codes, FR checks the final assembly of stages when they are cascaded into one system. The output frequency response can be compared with that expected from PZ.
Program BP	In the special case of bandpass filters, another mode of implementation is the multiple feed-back technique using the MAX267/268. Program BP calculates the resistor values and gives the frequency response which can be compared with that expected from PZ. This method requires only one clock frequency for all stages and allows for arbitrary gain.
Program FV	The graphics program FV can be used directly from the menu or from inside Programs PZ, FR and BP. It displays graphical representations of gain, phase and group delay using the files developed by PZ, FR and BP.
BROWSE in files	The output files generated by these programs can be examined conveniently using the BROWSE option from the main menu. Any output file can be scanned page by page without leaving the program.

SECTION 2. PROGRAM INSTALLATION AND OPERATION

Copy the Program to New Disks

(Caution: format command will erase all data on the disk.) Place a DS/DD or HD disk in drive a: and type the command: format a: Perform the following operations for each of the distribution disks. Place the program disk in b: and type the command: copy b:.* a: Keep the original disks in a safe place and use the copy.

Program Startup

For proper operation of the system, a hard disk is necessary.
Log in on drive c: (hard disk).
Create a subdirectory for the program files.

```
C:> md fltr {create a directory on disk c:
              called fltr}
```

Copy the files from the distribution disk into the new directory by doing the following steps with each disk.
Place the disk in drive a:

```
C:> copy a:.* fltr
```

Put the program disks in a safe place and use the version on drive c:

```
C:> cd fltr {log in to directory fltr}
```

The program requires subdirectories in which output files are collected.

```
C:\fltr> md dir1 {create a subdirectory
                  C:\fltr\dir1}
```

```
C:\fltr> filter {start program}
```

In response to first question type "dir1".

Program output will go into subdirectory C:\fltr\dir1

Operation with Floppy Disks

This is not recommended but can be done in a pinch. If the floppy is a high density drive then all of the files can be accommodated at once just as in the hard disk case. With DS/DD drives the graphics will not fit on the disk but the program can be run without graphics.

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Include the help files *.HLP on the disk. Create sub-directories as shown above for the output data.

Graphics

Program FV requires installation for the particular graphics adaptor present. Type FVINS to run the installation and answer the question for the type of adaptor.

When the graphics program FV is run from inside FILTER, both programs are in memory at the same time. If problems of insufficient memory are encountered, then first try removing any RAM resident programs such as SIDEKICK or SUPERKEY. If the problem continues then the graphics can be operated

directly from DOS provided the input files needed have been generated by FILTER. To run FV alone, from the DOS prompt type:

FV<enter>

If hard copy is to be obtained from the graphics, an IBM/Epson Graphics compatible printer is needed. For proper operation it is necessary to run the program GRAPHICS.COM supplied on the IBM system disk. To run this type:

GRAPHICS<Enter>

This command may be included in the startup file, AUTOEXEC.BAT.

SECTION 3 A SHORT HANDS-ON TUTORIAL, INCLUDING GRAPHICS

This section will benefit the user most if the computer is operating while following through the section. Detailed instructions are given in italic type on the exact moves and keystrokes to be made. Install the system as described in the previous section. In the present case we will collect files in a disk in drive b:. Place a formatted disk in b:.

Start up the program with the command: filter

The program asks for a disk or directory. Type the answer: b:

The program asks for a project_title. Type: Tutorial

The menu should come up and since we will use program PZ first, type the answer: 1

Step 1. Determine the basic filter characteristics using program PZ

Knowing the type of filter (lowpass, highpass, band-pass or notch), some very fundamental questions must be answered. Let us take a simple example of a lowpass filter and consider some of those questions. The program offers a choice of three types of design, Butterworth, Chebyshev and elliptic. Each of these can be compared using this example.

Let our imaginary filter have a corner frequency of 20KHz which means that we want it to pass signals in the band from DC to more or less 20KHz without undue variation in gain. Beyond 20KHz the gain is expected to fall off. Let us define 40KHz as the stop frequency, which is the frequency at which the gain falls off to a specified value. Usually it is desirable for the gain to fall steeply between the corner frequency and the stop frequency and improvements in this

regard require more complex filters, i.e., more filter stages.

Let us assume that we have available only two second order stages, which is the usual arrangement in one filter IC. We can use program PZ to see how much attenuation is obtained at 40KHz using the three filter types and compare their merits.

Let us say that in the passband (DC to 20KHz) we can allow 0.5dB of gain variation which is commonly called "ripple". Answering the appropriate questions in PZ we get the answers in file PZ1.R, PZ2.R etc. It turns out that the three filter types give the following attenuations at 40KHz.

Butterworth	15.08dB
Chebyshev	30.6dB
elliptic	48.64dB

These filters have the same number of stages but widely differing degrees of attenuation. They do so by adjusting the Q's in each stage and by locating the poles at different frequencies. In the elliptic case, two zeros are added which are not included in the Butterworth and the Chebyshev.

A filter is defined by the values of the poles and zeros measured in Hz and the values of Q associated with them. A 2nd-order section is characterized by a pole frequency and a value of Q associated with the pole pair. Program PZ provides a fairly painless means of deriving these values merely by answering some questions regarding the filter requirements.

We now show how to use PZ to get the above answers. For Butterworth, and a frequency response calculation from DC to 50KHz, type as follows after PZ starts.

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Keystrokes to PZ:

```
<ret> (for no help needed)/Butterworth/L/B/.5/20000/
y/4/40000/n/y/1/0/50000/50/n/n
```

(Note: in most cases where a negative answer "N" is required, a carriage return will also work. In most situations either upper case or lower case answers are equivalent.)

We answer that we know the order and that it is 4, since we have two second order stages. On other occasions we will not know the order and will need the program to calculate the order given a requirement for a certain attenuation. The program writes some answers to the screen and also sends output to our designated disk, in this case b:. So there will be on disk b: two files called PZ1.R, with the data for the filter, and file PZ1A for the frequency response data. In the above example both of these files will have the title "Butterworth" and will have the same date and time in their heading. In the above case the graphics option was not chosen. The frequency response graphs can be observed either inside programs PZ, FR and BP or directly from the menu. We will show below how to use FV from the menu.

We repeat these same instructions for the Chebyshev and elliptic cases with similar keystrokes.

Keystrokes to PZ:

```
<ret>/Chebyshev/L/c/.5/20000/y/4/40000/n/y/1/0/
50000/50/n/n
```

Keystrokes to PZ:

```
<ret>/elliptic/L/e/.5/20000/y/4/40000/n/y/1/0/
50000/50/n/n
```

We now have bunch of files on b: with names like: PZ1.R, PZ1A, PZ2.R, PZ2A, PZ3.R, PZ3A. In the menu

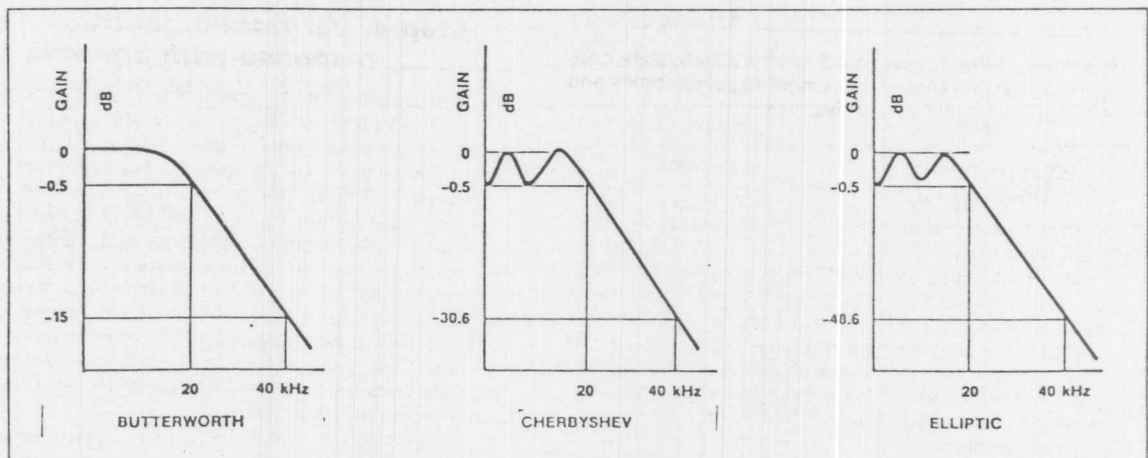
there is a BROWSE option which allows the contents of these files to be examined. Try this option before reading the following section.

We see in the output files that the attenuation is successively greater with Butterworth, Chebyshev, and elliptic. If we need more than 15dB of attenuation then Butterworth would require more than two stages. The following table summarizes the costs and benefits of the three filter types:

Filter Comparison

	Advantage	Disadvantage
Butterworth	More constant gain in pass band. Best transient response.	Least attenuation in stop band.
Chebyshev	Better attenuation in stop band.	More ripple (less consistent gain in pass band).
elliptic	Most attenuation in stop band.	More ripple in pass band. Requires zeros and therefore extra op amps and resistors.

The frequency response files PZ1A etc. show the way gain changes with frequency. In the Chebyshev and elliptic cases there are peaks and valleys equal to what was entered into the program as "ripple", in this case 0.5dB. The following figure summarizes what we have found from program PZ.



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At this point the designer judges which filter type to use. Suppose the required attenuation is 25dB. Then the Butterworth design requires more stages and the Chebyshev or elliptic may be more suitable. However since the elliptic requires two amplifiers and some resistors to create the zeros, for this example we will settle on Chebyshev and move on to the next step of the design.

Before moving on we will check out the graphics program FV from the main menu. Type 7 to get it. Read the general information on the screen and press RETURN to get the graphics menu. The cursor should be on DIRECTORY showing our current file directory and the filenames should appear below. Move using arrows to the heading PLOT TYPE and successively type 1,2,3 and see the options. Stop on 1 for the simplest option. Use arrows to reach heading FREQUENCY and successively type 1,2 to see the log/linear options. Select linear. Use arrows to go down to the files and stop on the first file. Select it with a + and it will be highlighted. Now go to graphics using the function key F1. The frequency response calculated in PZ should now be displayed.

To go back to the menu just press F1 and at the menu select another file using the arrows and +. Go back to graphics with F1 and two file plots should now be observed. Repeat these moves for practice selecting and deselecting files with +/-keys. To reset the conditions use F3 key. Read the prompts which are visible at any stage to find the appropriate keys. To leave the graphics package press F10 until the menu reappears. For more detailed instructions on Graphics, see the graphics section of this manual (Section 12).

Step 2. Choose an IC and a mode

Looking at the output of PZ for the Chebyshev case we see that there is a requirement to create poles and Q's approximately as follows:

Pole	Q
20625Hz	2.9406
11940Hz	0.7051

Let us assume that the only clock available has a frequency of 1MHz, which implies that the approximate clock ratios for the above stages will be 48 and 84. With Maxim's products we have the choice of several devices. These include parts where the poles and Q's are programmed digitally in conjunction with resistors and others where these are programmed purely digitally. In the latter case the implementation is simpler. Let us see whether that approach will meet the requirements.

The product tables in Section 4 show examples of digitally programmed parts MAX260 through MAX264.

The frequency of the system is fairly high so we can choose parts which are capable of high frequencies, MAX262 or MAX264. In mode 1 these devices have a clock to center frequency range of 40 to 140 so they fit the application.

The data sheets of the above mentioned parts can help select the appropriate mode for the application. The available modes are Modes 1, 2, 3, 3a and 4. Lowpass filters can be implemented with any of these modes. We choose Mode 1 because it has a lowpass gain of unity and can support a high frequency clock.

Step 3. Determine the Q and Clock Ratio codes with program MPP

Assuming a clock of 1MHz with the MAX262, we employ program MPP to aid in programming the digital codes. We select MPP from the menu and enter the following data: (We assume a printer is attached and answer the question on printing with y. If no printer is attached then answer n.)

Keystroke input to MPP:

```
<ret> (for no help)/Chebyshev LP/1/6/1/2/20625/  
2.9406/11940/.7051/1/1000000/1000000/y
```

The output from MPP shows digital codes to set Q's and clock ratios. We find that the center frequencies and Q's achieved by the circuits are reasonable approximations of the required values. Notice that the program 'aims' at one center frequency in order to get another. For instance in the second stage, the targeted center frequency and the appropriate clock ratio is for 11368Hz but the circuit actually delivers a center frequency of about 11895Hz. This is how the program compensates for known sampling errors.

Step 4. Verification of frequency response with program FR

This last step is used to confirm the design. In MPP the required parameters were only approximated so the final filter response will differ from the ideal. The center frequencies of the two sections were off by 1.4% and 0.38% so the exact frequency response obtained in program PZ will not be obtained. This program checks the actual response and a judgement can be made whether it is adequate for the application. Program FR asks questions which can be answered using the output of MPP. We will now key in the data for the two stages and FR will calculate the frequency response. We will use the same frequency response parameters as were used in PZ so a direct comparison can be made.

Keystroke input to FR: <ret>/tutorial/2/2/L/n/20914/
2.9964/1/2/2/L/n/11895/.7069/1/e1/0/50000/50/
n/n/n

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This last frequency response can be compared with that from PZ and most users would probably agree that they correspond closely enough for most engineering applications. (Note the 0.5dB offset on the response from PZ, which may be removed by rerunning PZ and using the option to normalize the response at zero Hertz.)

Step 5.

Implement the hardware

Set up the chosen device (MAX262 in this case),

provide the clock, the digital settings for the clock ratios, Q's and modes and check the frequency performance.

The MAX260/1/2 data sheet illustrates an aid in bench testing a filter ("QuickLook"). The codes for mode, f_0 and Q are applied to the IC using the parallel printer port of a PC. A small BASIC program, PR.BAS, is used to generate the codes for programming the filters in a convenient way. A listing of PR.BAS is included in the distribution disks of FILTER. The file PR.EXE can be executed directly by typing "PR".

SECTION 4

SUMMARY OF MAXIM'S FILTER PRODUCTS

μ P PROGRAMMABLE FILTERS:	MAX260	MAX261	MAX262
Filter type (Dual 2nd-Order)	Universal	Universal	Universal
Clock/Center freq. ratio, approx	100-200	100-200	40-140
Clock/center freq. ratio—Mode 2 only	71-142	71-142	28-100
Max Center Frequency for $Q < 8$	7.5 KHz	30 KHz	75 KHz
Q Register (Filter A,B independent)	7 bits	7 bits	7 bits
Clock Ratio Register (Filter A,B independent)	6 bits	6 bits	6 bits
Independent mode selection, Filter A,B	Yes	Yes	Yes
Independent Clock, Filter A,B	Yes	Yes	Yes
Uncommitted op amps	None	1	1
Crystal or RC Clock	Yes	Yes	Yes
PIN PROGRAMMABLE FILTERS:	MAX 263	MAX264	
Filter type (Dual-2nd order)	Universal	Universal	
Clock/Center Freq. Ratio	100-200	40-140	
Clock/center freq. ratio—Mode 2 only	71-142	28-100	
Max Center Frequency for $Q < 8$	30 KHz	75 KHz	
Q Register (Filter A,B same value)	7 bits	7 bits	
Clock Ratio Register (Filter A,B same value)	5 bits	5 bits	
Independent Clock, Filter A,B	Yes	Yes	
Independent mode selection, Filter A,B	No	No	
Crystal or RC Clock	Yes	Yes	

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Resistor Programmable Filters:	MAX265	MAX266
Filter type (Dual 2nd-order)	Universal	Universal
Clock/Center freq. Ratio (Can be changed with resistors)	100-200	40-140
Max Center Frequency for $Q < 8$	30 KHz	75 KHz
Q Setting (Filter A,B independent)	Set with resistors	Set with resistors
Clock ratio pin setting, same both sides, further independently modifiable with resistors	6 bits	6 bits
Independent Clock, Filter A,B	Yes	Yes
Uncommitted op amps	2	2
On-chip crystal or RC oscillator	Yes	Yes
Programmable Bandpass Filters:	MAX267	MAX268
Filter type (Dual 2nd-order)	Bandpass only	Bandpass only
Clock/Center Freq. Ratio	100-200	40-140
Max Center Frequency for $Q < 8$	30 KHz	75 KHz
Q Register (A and B Same Value)	7 bits	7 bits
Clock Ratio Register (Filter A,B Same Value)	5 bits	5 bits
Uncommitted op amps	1	1
Crystal or RC Clock	Yes	Yes

SECTION 5 SUBPROGRAM PZ

This program helps define the individual second order stages that are cascaded for specific filter functions. In the case of odd order filters one first order stage will also be included. Data is entered in response to questions such as:

- Filter shape (lowpass, highpass etc.)
- Polynomial (Butterworth, Chebyshev, elliptic)
- Maximum allowable passband ripple
- Minimum attenuation in the stopband

Once this information is entered, the program calculates the required order and the poles and Q for each section. In bandpass filters, the program also calculates the numerical factor (Gain Adjustment Factor) needed for computing the proper gain at the system center frequency when stages with differing individual center frequencies are cascaded.

At the option of the user, the frequency response of the filter is also calculated, providing information on amplitude, phase and delay. Several different response checks can be made, focusing on different frequency ranges if desired.

Normalizing Frequency Response Data

The gain from the filter analyzed by PZ is undefined. In the program, the method of normalizing found in most texts is used. For odd order filters the gain is 0 dB at the center frequency and for even order filters is minus the ripple at center frequency. The program allows normalization at any other frequency as an option.

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Special Note Regarding Bandpass Filters

When high order bandpass filters are made by cascading two or more second-order bandpass sections, with either the same or different center frequencies, the gain at center frequency of the overall filter is a matter which requires careful consideration. The gains of the individual sections are set using programs RP or MPP. If the gains of the individual stages are merely multiplied together in the expectation of arriving at the gain for the overall bandpass filter then the result will likely be in error. The reason is that the gains for each stage are calculated at the particular center frequency of each stage, not at the frequency of interest which is the center frequency of the overall function.

Program PZ calculates a number called the Gain Adjustment Factor (GAF) which helps in calculating the gain at the true center frequency of the overall filter.

The following definitions are for ONE SECTION of the overall filter.

- K= gain factor of section
- Q= Q of section
- ω_p = center (angular) frequency of section
- ω_z = (angular) frequency of zero of section (if there is one)

For the overall filter (all the sections together)
 ω_{obp} =center frequency

Define ratios of the above frequencies as follows:

$$F = \omega/\omega_{obp} \text{ and } F_z = \omega_z/\omega_{obp}$$

Case 1: a section with no zero (a Chebyshev or Butterworth section or the odd section of an elliptic which has no zero)

The transfer function of the section is given by:

$$H(s) = \frac{K \frac{\omega_p}{Q} S}{S^2 + \frac{\omega_p S}{Q} + \omega_p^2}$$

and substituting $s = j\omega$ get:

$$H(\omega) = \frac{jK\omega_p\omega/Q}{(\omega_p^2 - \omega^2) + j\omega_p\omega/Q}$$

At frequency $\omega = \omega_p$:

$$H(\omega_p) = \frac{jK\omega_p^2/Q}{j\omega_p^2/Q} = K$$

$$|H(\omega_p)| = K$$

At frequency $\omega = \omega_{obp}$:

$$H(\omega_{obp}) = \frac{jK\omega_p\omega_{obp}/Q}{(\omega_p^2 - \omega_{obp}^2) + j\frac{\omega_p\omega_{obp}}{Q}} = \frac{jKF/Q}{(F^2 - 1) + j\frac{F}{Q}}$$

$$|H(\omega_{obp})| = \frac{KF/Q}{\left[(F^2 - 1)^2 + \frac{F^2}{Q^2}\right]^{1/2}}$$

So the Gain Adjustment Factor for the stage is then:

$$GAF = \left| \frac{H(\omega_p)}{H(\omega_{obp})} \right| = \frac{Q}{F} \left[(F^2 - 1)^2 + \frac{F^2}{Q^2} \right]^{1/2}$$

Case 2: a section with a zero such as in an elliptic filter.

The transfer function of the section is given by:

$$H(s) = \frac{K(S^2 + \omega_z^2)}{S^2 + \frac{\omega_p}{Q}S + \omega_p^2}$$

and substituting $s = j\omega$ get:

$$H(\omega) = \frac{K(\omega_z^2 - \omega^2)}{(\omega_p^2 - \omega^2) + j\omega_p\omega/Q}$$

At frequency $\omega = \omega_p$:

$$H(\omega_p) = \frac{K(\omega_z^2 - \omega_p^2)Q}{j\omega_p^2}$$

$$|H(\omega_p)| = \frac{KQ(\omega_z^2 - \omega_p^2)}{\omega_p^2} = \frac{KQ(F_z^2 - F^2)}{F^2}$$

At frequency $\omega = \omega_{obp}$:

$$H(\omega_{obp}) = \frac{K(\omega_z^2 - \omega_{obp}^2)}{(\omega_p^2 - \omega_{obp}^2)^2 + j\frac{\omega_p\omega_{obp}}{Q}}$$

$$|H(\omega_{obp})| = \frac{K(\omega_z^2 - \omega_{obp}^2)}{\left[(\omega_p^2 - \omega_{obp}^2)^2 + \left(\frac{\omega_p\omega_{obp}}{Q}\right)^2\right]^{1/2}}$$

$$= \frac{K(F_z^2 - 1)}{\left[(F^2 - 1)^2 + \frac{F^2}{Q^2}\right]^{1/2}}$$

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So the Gain Adjustment Factor for the stage is then:

$$\text{GAF} = \left| \frac{H(\omega_p)}{H(\omega_{OBP})} \right| = \frac{Q(F_z^2 - F^2) \left[(F^2 - 1)^2 + \frac{F^2}{Q^2} \right]^{1/2}}{F^2(F_z^2 - 1)}$$

Program PZ calculates the GAF for the whole filter which is the product of the GAF factors for each individual section calculated according to the above formulae. To use the GAF in practice, calculate the product of the gains of all of the stages and divide the product by the GAF to obtain the gain at the center frequency of the overall filter.

For example, the overall filter has center frequency of 1000 Hz:

First stage: center frequency is 771 Hz, gain at 771 Hz is 1.0

Second stage: center frequency is 1296 Hz, gain at 1296 Hz is 2.0

GAF as calculated by program PZ is 2.92

Then gain for system is $1.0 \times 2.0 / 2.92 = 0.685$ at 1000 Hz

PROGRAM OUTPUT FROM PZ

A brief report appears on the screen and a more detailed report is sent automatically to disk files named PZ1.R, PZ2.R etc. and directly to a printer on request.

Frequency response data relating to the designs will be in files:

PZ1A, PZ1B etc. for design PZ1.R

PZ2A, PZ2B etc. for design PZ2.R, and so on.

The user can connect the frequency response files to the proper design file by referring to the time/date stamp at the head of each file. Alternatively a title can be written at the top which appears on all files from the same design.

When the program is exited and restarted the same file names are repeated. The program automatically renames the old files so they are not lost. A letter is added to the end of the filename to produce a unique name. The files can be examined while still in the program using the BROWSE option at the menu. After leaving the program and returning to DOS the output files may be accessed by commands such as the following:

A:\> type b:pz1a

Output appears on screen.
Start and stop scrolling
with CONTROL-S

A:\> print b:pz1a

If a suitable printer is
connected

A:\> copy b:pz1a prn

If a suitable printer is
connected

SECTION 6 SUBPROGRAM RP

This program helps apply Maxim's resistor programmed filter products (MAX265/266). Program input is given in response to prompts relating to:

Filter shape (lowpass, highpass etc.)
Center frequency or corner frequency
Frequency of zero
Q
Mode

There are various modes of operation, Mode 1, Mode 2 etc. which define the way the external resistors are used to perform the filter functions. The device data sheets can be consulted for help in choosing the appropriate mode.

The program will calculate the resistor values. The set of resistors is not unique. Others would work as well provided the ratios between the values are preserved. Note however that the filter output swing may be limited for resistive loads below 10kohm while too high values could result in poor noise performance.

Clock/Center Frequency Ratio

This ratio is set digitally in the MAX265/266. The available ratios are:

MAX265 Approximately 100-200
MAX266 Approximately 41-140

Depending on the mode, these ranges are further adjustable with the external resistors. The data sheet information describing operating modes should be consulted.

Error Correction

In all switched capacitor circuits, sampling errors cause the actual center frequencies and Q's to differ from the ideal values given by design texts or tables. Such errors are a predictable function of Q, and clock/center frequency ratios and are largest with low selected Q's and low clock/center frequency ratios.

This program is unique in that it takes these sampling errors into account. Just as a marksman aims high when using a rifle which he knows tends to shoot low,

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the program pre-compensates the output data so that the final result is on target. The corrections will be evident in the printed output when compared with "ideal" values from other design sources which do not assume a sampled system.

Gain of Notch Filters in Mode 3A

When the program requires information to set the gain of notch filters it asks questions relating to:

The frequency at which the gain is to be set (DC or high frequency)

The gain which is to be given priority (low freq, high freq, center freq)

Without further complicating the problem a simple rule to follow in answering these questions is to set gain at zero Hertz or DC and to set the lowpass gain as the priority. If this is done for ALL the second order sections of a multi-section filter then the correct overall gain will be achieved. (An equally correct but different solution will be obtained when the gain is set

at half the clock frequency and the highpass gain is set as the priority, provided this is done consistently.)

Gain of Bandpass Filters

When a bandpass filter composed of two or more second order sections is designed, the gain of the overall filter at the design center frequency needs careful consideration and these programs will provide aid in arriving at the proper gain. See the note on bandpass gain in Section 5.

Program Output from RP

After the data has been entered the program calculates the resistors and the results appear on the screen. There is an opportunity to print the data if a printer is attached. The same data is automatically sent to disk files:

First design in file RP1.R

Second design in file RP2.R, etc.

SECTION 7 SUBPROGRAM RPCHECK

This program helps in applying the Maxim filter products which are programmed using resistors, MAX265/266.

The companion subprogram RP calculates the resistors needed to perform a specific filter function. RPCHECK is the complement of RP. Given an operating mode and a set of resistors, RPCHECK calculates the performance of the filter stage. RPCHECK is useful in checking the sensitivity of a design to resistor tolerances.

Program Output from RPCHECK

After the data has been entered the program calculates the performance and the results appear on the screen. There is an opportunity to print this data if a printer is attached. The same data is automatically sent to a disk files:

First design: CHECK1.R

Second design: CHECK2.R, etc.

SECTION 8 SUBPROGRAM MPP

This program helps apply Maxim's μ P and pin-programmable filter products (MAX260-MAX264). PZ can be used to first define a filter function and to separate it into its second- and first-order components. MPP will then implement the sections either one at a time or in pairs. For filters requiring several pole pairs the program can be run repeatedly.

Responding to prompts, the user enters the center frequency, Q and either the clock frequency or clock/center frequency ratio. Available modes are 1, 2, 3, 3A and 4.

Allowed parameter ranges are roughly as follows:

For Mode 1, 3, 3A, 4:

Q = 0.5 to 64

Clock ratio = 100 to 200 (MAX260/61/63)
= 41 to 140 (MAX262/64)

For Mode 2:

Q = 0.7 to 90

Clock ratio = 71 to 140 (MAX260/61/63)
= 28 to 100 (MAX262/64)

To implement Mode 3A an internal or external op amp and external resistors are used.

Error Correction

In all switched capacitor circuits a sampling error causes the actual center frequencies and Q's to differ from the ideal values given by design texts or tables. Such errors are a predictable function of Q and clock/

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center frequency ratio and are largest with low selected Q's and low clock/center frequency ratios.

This program is unique in that it takes these sampling errors into account. Just as a marksman aims high when using a rifle which he knows tends to shoot low, the program pre-compensates the output data so that the final result is on target. The corrections will be evident in the printed output when compared with "ideal" values from other design sources which do not assume a sampled system.

Errors Relating to Quantization

When clock frequency is specified and the program selects the clock ratio, there may be an error in final center frequency due to the 5-bit or 6-bit resolution of the clock ratio. This error can be taken out by a small change in the clock frequency if that is allowable.

When the user defines the clock ratio, then the program will find the closest quantized value and calculate the clock frequency results in zero center frequency error.

Power-Down Function

The programming code 0000000 for Q is used for a power-down function in all parts. Special care must be taken in not using it to set Q. In the microprocessor programmed parts, MAX260/262/162, this restriction applies only to side A. In side B the 0000000 code

does result in a valid Q value and the filter is not shut down.

Gain of Notch Filters in Mode 3A

When the program requires information to set the gain of notch filters it asks a question relating to the frequency at which the gain is to be set (DC or high frequency)

Without further complicating the problem a simple rule to follow in answering these question is to set the gain at zero Hertz or DC. If this is done for ALL the second order sections of a multi-section filter then the correct overall gain will be achieved.

Gain of Bandpass Filters

When a bandpass filter composed of two or more second order sections is designed, the gain of the overall filter at the design center frequency needs careful consideration and these programs will provide aid in arriving at the proper gain. See Section 5.

Program Output from MPP

The output of the program is sent to the screen and an opportunity is given to send it to a printer if one is available. The results are automatically sent to files:

First design: file MPP1.R
Second design: file MPP2.R, etc.

SECTION 9 SUBPROGRAM FR

After a series of stages are designed with the help of subprograms PZ, RP, RPCHECK and MPP, the overall response of the cascaded sections can be checked using this subprogram. The outputs of the above subprograms will be the input of this subprogram. In some cases the input data may come from other sources, for instance in the case of a simple RC section. The data is entered by answering specific questions for each section in turn. So it would be well to have on hand the printouts from the above subprograms where needed.

After all stages are entered the final answer given is 'end' or 'E'. The program then computes the response

of the cascaded stages. This can then be compared with the response predicted by PZ to confirm that the design is correct. More than one frequency response calculation can be made, focusing on different frequency intervals if desired.

Program Output from FR

The design data is sent to files which summarize the data and list the frequency response data for the interval specified. If desired, frequency response data can be computed for several different intervals.

First design output files: FR1A, FR1B, and so on.
Second design output files: FR2A, FR2B, and so on.

SECTION 10 SUBPROGRAM BP

Bandpass filters can be designed using the following techniques:

- (i) cascading second order sections, each section having a different center frequency.

- (ii) cascading second order IDENTICAL sections and using resistive feedback in the multiple feedback technique.

With technique (i), a MAX26X cannot always imple-

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ment a bandpass using a single clock input. The different center frequencies may require separate clocks for each filter section. (The design procedure for MAX260 is supported by Program MPP). With technique (ii) a high order bandpass needs only one clock along with a few external resistors. This program, BP, assumes that technique (ii) is used.

With the MAX267 and MAX268 bandpass filters the clock ratio and Q are set by strapping programming pins to high or low logic levels. The clock to center frequency ratio can be set as follows:

100-200 for MAX267
41-140 for MAX268

When a multiple feedback topology is used (BP assumes this topology), then all second order stages have the same Q and the same clock/center frequency ratio. The 7-bit code for Q and the 5-bit code for the clock/center frequency ratio are derived by the program.

BP also derives a set of resistor values. The absolute values are not unique and others will work as well provided the ratios are maintained. Consideration must be given to output loading effects for resistor values less than 10kohm.

Program Output from BP

The resistor specs are written out on files

BP1.R for first design
BP2.R for second design, etc.

Frequency response files are also written to disk and it is possible to have several frequency response files for each design:

Design BP1.R has frequency response files BP1A, BP1B etc.
Design BP2.R has frequency response files BP2A, BP2B etc.
and so on for subsequent designs

SECTION 11 SUMMARY OF OUTPUT FILES FROM ALL PROGRAMS

PZ	First run of PZ: report file is PZ1.R and frequency response files are PZ1A, PZ1B,.....PZ1I etc. for 9 possible runs Ninth run of PZ: summary file is PZ9.R and frequency response files are PZ9A, PZ9B,.....PZ9I
RP	First run report file is RP1.R and so on for 9 runs Ninth run report file is RP9.R
RPCHECK	First run report file is CHECK1.R and so on for 9 runs Ninth run report file is CHECK9.R
MPP	First run report file is MPP1.R and so on for 9 runs Ninth run report file is MPP9.R
FR	First run output files for different frequency response conditions are FR1A, FR1B etc for 9 possible files to FR1I for 9 runs down to FR9A, FR9B, FR9I
BP	First run gives BP1.R and then BP1A.....BP1I Ninth run gives BP9.R and then BP9A.....BP9I

Notes on Output Files

As noted above the programs generate two types of files, report files and frequency response files. The program names the files automatically starting with '1' and 'A' and then successively goes to 2, 3 ... and B, C, ... Report files give design information and have a subscript ".R" while frequency response files which can be used by the graphics package (FV) have no subscript.

Automatic Renaming of Output Files

The program names the files automatically and always uses the same names. Consequently old files in the directory would be overwritten and lost if the program did not rename them. Therefore the program does

check to see if a file of the same name exists and renames it by adding a letter to the end of the name so that the name is unique in the directory.

Examples: PZ1.R may be renamed PZ1.RA; BP1A may be renamed BP1A.C

The first letter which results in a unique name is appended for renaming.

Browsing in Files

It is often necessary to use the output of one program as the input for another one. For instance, the output of PZ in file PZ1.R would be needed to provide the pole, zero, Q information for either MPP or RP. The existing output files can be conveniently examined directly from the main menu by using the BROWSE

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option which gives access to all files in the working directory. Data can be noted by hand or the PRINT SCREEN feature of the keyboard may be used to print the pertinent passages.

Use of Titles on Files

The first line of every output file is a main title which would normally be the title of the overall project. This title also appears on the top of the graphics display. The user gets the opportunity to make this title at the startup of FILTER.

The second line of every output file has the date and time of the start of the subprogram and the subtitle which can be written at the start of each subprogram. The same first and second line titles, with the same time and date will be on all files of the same run and can be used to connect the design data to the proper frequency response data. The second line title helps to identify files in the BROWSE option and in FV graphics.

Introduction

Program FV is an independent program with its own executable file, FV.EXE, which can be used with FILTER or independently. It may be used in any of three ways to display files made by FILTER.

- a. From FILTER's main menu
- b. From inside subprograms PZ, FR and BP
- c. From the DOS prompt independently of FILTER

When FV is run from inside FILTER, both programs are in RAM together and the system needs sufficient RAM to achieve this. If difficulties are encountered when FV is called from inside FILTER because of insufficient memory, the problem can probably be resolved by running FV after leaving FILTER, so long as the proper input files for FV have been generated.

FV requires files of numbers which will be displayed as graphic curves. These must be of the form generated by FILTER and can be inspected by the interested user. The filenames must also conform to a standard. They must be of one of these forms:

PZ?? FR?? BP??

where the question marks may be any legal character. The filenames must have no suffix. The consequence of this is that when FILTER renames files by adding a letter to their names (to avoid duplicate names) the names become unusable by FV. If they are to be displayed using FV then the name must be changed to conform to one of the above styles.

When FV is used with FILTER, the title at the heading of the graph is taken from the first line of the first input file in the list. This header can be changed by the user at the FV menu.

SECTION 12 "FilterView" GRAPHICS PACKAGE

FilterView Graphics Postprocessor

1.0 Overview

FilterView (FV) is a graphics post-processor utility that aids users of the MAX260 programmable filter family when using the FILTER software. FilterView displays the frequency response of the filters designed using the FILTER software. It allows for comparing the effects of choosing different component values, filter coefficients and clock frequencies in easy to understand visual format.

2.0 Hardware Requirements

FilterView requires an IBM PC/XT/AT or compatible with 256K memory (512K recommended), DOS Version 2.1 or higher and one of the three graphics boards (or compatible) and suitable monitor:

1. IBM Color Graphics Adapter (CGA)
2. IBM Enhanced Graphics Adapter (EGA)
3. Hercules Graphics Adapter (HGA)

Use program FVINS (included on the distribution disk) to install the program for the proper graphics adaptor. Type FVINS and answer the question.

If hardcopy is required an IBM/Epson Graphics compatible printer is also needed.

A math co-processor is not required but vastly improves plotting speed in the display mode.

3.0 User's Guide

FilterView is a menu-driven software package. It has two modes, main-menu mode and graphics mode. The main-menu mode allows the user to choose various output modes and select files to be viewed. The graphics mode displays the filter response and allows for zooming, on-screen measurements and hardcopy output.

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3.1 Running FilterView

FilterView can be started by typing FV from the operating system:

FV<Enter>

FilterView has the capability to pass filenames from the command line. This means that the directory where the FILTER output files are located can be passed to the program by typing:

FV dir1<Enter>

or,

FV @setup-file<Enter>

where a @ character before the file-name specifies a setup-file. (The setup-file is explained in the following sections).

3.2 Main Menu

When FilterView is started the screen shows the main-menu. The Main-Menu has three windows: parameter window, option window and plot files window. Additionally at the bottom of the screen a summary of the active function-keys is displayed. (these keys are special function keys labeled F1, F2,...F10 on the keyboard.)

The highlighted entry indicates the current position of the cursor. The cursor can be moved by the left, right, up and down arrow keys on the numeric pad of the keyboard.

3.2.1 Parameters and Options Windows

The Parameters window has 6 entries:

- 1) **Directory** specifies the directory or drive where the files from the FILTER program are located. When the cursor is on Directory, the options menu displays:

dir Specify where FILTER outputs are
@file[.FVS] Load setup file
F4 Save current setup

A setup file is generated by FilterView to hold the current settings such as active directory, frequency plot type, selected plot files, plot type and titles. The setup file makes it possible to by-pass the lengthy parameter setting process when FILTER and FilterView are iteratively used. The default file extension for the setup file is [.FVS]. Typing a @ character before the filename specifies that the filename stands for a setup file and not a directory path. The current settings can be saved by using the F4 key where FilterView prompts for the setup filename:

Saving current setup
Filename _____

Note that when specifying the setup filename, the @ character before the filename *must not be used*.

- 2) **Frequency** specifies if a logarithmic or linear scale is to be used on the frequency axis. The options window displays:

Enter desired plot type (1,2)
1-Linear frequency
2-Logarithmic frequency

Pressing <1> or <2> will choose the desired plot type.

- 3) **Plot Type** specifies which outputs are to be displayed. The options menu displays:

Enter desired plot type (1-3)
1-Amplitude only
2-Amplitude and Phase
3-Amplitude and Group Delay

Pressing <1>, <2> or <3> will choose the desired plot type.

- 4) **De-Normal** specifies if the amplitude response should be normalized or displayed in absolute terms. Program FILTER has an option for normalizing. This command allows the normalizing to be cancelled so the absolute amplitude is displayed.

Do you wish the amplitude denormalized (Y/N)?
(Only applies for FILTER files generated in normalized form)

If <Y> is chosen, all responses will be displayed with absolute amplitude regardless of whether they were or were not normalized by FILTER. The command cannot normalize amplitudes which were not normalized in FILTER.

- 5) **Freq Windw** specifies the minimum and maximum range of frequencies to plot. The options menu displays:

<Enter> Alter windowing
A Reset to auto-scale

For logarithmic plots, the minimum and maximum frequencies must be positive numbers (Zero not allowed).

- 6) **Change Options** entry is used for specifying or modifying other optional parameters. When the cursor is on this entry, pressing <Enter>, as prompted, moves the cursor into the options window.

In the options window the user can input a plot title, choose grid and color options.

- Plot title (TITLE) is displayed at the top of the plot as a single line. A title can either be typed or an old one be edited by using the F2 key. The edit mode operates similar to a text editor.

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- The GRID option is used to toggle on and off the grid that is normally displayed on the plot. Press <Y> or <N>.
- The COLR entry is used to select between different color palettes offered with graphics cards. Up to fifteen separate traces can be displayed at a time.

3.2.2 Plot Files Window

This window allows the user to select which files are to be plotted. After the last parameter selection the cursor rolls down to this window, and the options window shows:

F3 End selection
F4 Untag all files
= Tag file for plot
Untag file for plot

Each of the lines in the plot variables window corresponds to a FILTER program output file. The first line in this window labels the entries as # (file number), FILE (filename) and TITLE (title read from file). For example:

```
1 PZ1A 2/25/88 9:14 Bandpass Filter Ideal
2 BP1A 2/25/88 9:22 Actual response
   using MAX267
```

There can be up to 10 files. These filenames are automatically read from the specified directory and displayed in this window and are not specified by the user. If there are more than 10 files, the obsolete files in the given directory must be deleted to reduce the number of files to 10. Files in different directories cannot be plotted simultaneously. To plot files from different directories, then they must be copied into one directory, using the name convention described above (PZ?? FR?? BP??). Conversely, to hide files from FV without deleting them, they should be renamed to disagree with the name convention. For example, PZ1A.X, PZ1AY, AB CD are names which FV will ignore.

If a file output is to be displayed, pressing the <+> key in the numeric keypad tags it. Conversely, the <-> key untags that file from the display. Pressing <F4> untags all file selections.

Up to 15 variables can be displayed at a time. This means that if amplitude only is selected, all file outputs can be plotted, whereas if amplitude and phase or group delay is selected only 7 file outputs can be plotted.

Pressing function key F3 ends selections and moves the cursor back to the parameter window.

3.3 Displaying Plots

Once all necessary selections are made in the main-menu, pressing function key F1 switches FilterView into the graphics mode and displays the plots.

The frequency is displayed in the x-axis (linear or logarithmic). The amplitude is displayed in the y-axis. If group delay or phase is chosen, they are displayed in the same plot with the scale appearing in the right side of the plot.

The active function keys appear at the bottom of the menu as shown below:

F1 Exit F4 Ruler F5 Zoom Ampl
F6 Zoom PH/GD F9 Print

where F1 key returns to the main-menu, F5 activates the on-screen zoom function for the AMPLITUDE axis and frequency axis, F6 activates the zoom function for the PHASE or GROUP DELAY axis and the frequency axis, F4 activates the ruler function, and F9 sends the plot on the screen to the printer. Note that before the screen is printed, the help menu is cleared.

3.3.1 Zoom-Menu

Whether the amplitude or phase/group delay zoom function is invoked the bottom help menu displays:

<arrows> Move <Enter> Set F3 Quit
F5 AutoXY F6 AutoY

At the same time, a cursor composed of a vertical and horizontal solid line appears on screen. This cursor can be moved around the screen using the arrow keys. If the arrow keys are held down the cursor moves faster.

The cursor is used to define a zoom window by specifying two diagonal corners of a rectangle. This is done by first positioning the cursor at the lower-left corner of the desired zoom window and pressing the <Enter> key. Immediately following this action, the cursor position is set on the screen, and a second cursor appears upper right. The arrow keys can again be used to move this cursor around and set its position—the upper right corner of the desired zoom window—by pressing the <Enter> key.

The screen first clears and then redraws the zoomed view of the plot. The Zoom-Menu can be repeatedly used to obtain finer and finer resolution of any area of the plot.

Pressing function key F3 quits Zoom-Menu selection and returns to the previous state of FilterView.

Pressing function key F5 (AUTO XY) resets the zoom window back to the automatic X- and Y-axis settings any time while in the zoom mode. Automatic scaling is set only for the chosen zoom menu (amplitude or phase/group delay).

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Pressing function key F6 (AUTO Y) resets the zoom window back to automatic *only* for the Y-axis, and leaves the frequency X-axis unchanged.

3.3.2 Ruler-Menu

When in the graphics mode pressing function key F6 displays the ruler-menu which looks as shown below:

```
<---||> Move <Enter> Fix F3 Quit F9 Print
```

At the same time the ruler-menu a cursor appears on the screen. This cursor can be moved using the arrow keys. If the arrow keys are held down the cursor moves faster, if they are pressed momentarily the cursor moves slowly.

The lower-left side of the screen also displays a pop-up window with the current X- and Y-axis values of the cursor position next to the number 1. This allows the user to find the approximate value of any point on the screen. If the <Enter> key is pressed, this cursor becomes fixed and the solid lines transform into dashed lines. A second cursor appears on the upper-right of the screen and can be moved around similarly. The X- and Y-axis values of this cursor are displayed in the pop-up window next to the number 2. Moreover, the difference of the values of the first cursor position and the second cursor position are displayed next to the letter D (delta or difference) in this window. This feature can be used to make on screen measurements, such as the amplitude difference. If the frequency axis is logarithmic a ratio is displayed rather than a difference.

Pressing function key F9 sends the plot on the screen to the printer. Note that before the plot is printed the function-menu on the screen is cleared.

Pressing function key F3 quits the ruler-menu selection and returns to the previous state of FilterView.

3.3.3 Printing Hardcopy

The printer used for hardcopies must be one that supports IBM/EPSON graphics, such as most dot-matrix printers.

Before you can use this feature, you must run the GRAPHICS.COM program supplied on your IBM system disk by typing:

```
GRAPHICS<Enter>
```

If you are making use of an AUTOEXEC.BAT file, you can include this line in it.

3.3.4 Exit from FilterView

Pressing function keys F8 or F10 exits from FilterView into the operating system.

If F8 key is pressed FilterView enters the DOS temporarily where all DOS commands can be used as normal. You must have sufficient memory available to be able to load the system and any other program you may wish to execute. Note that the prompt is changed to:

```
FV.DOS=>
```

to remind you that you are not in DOS but still in FilterView. Pressing the <Enter> key at this prompt puts you back into FilterView. This feature is useful to look at the output or setup filenames to refresh your memory with:

```
DIR *.FVS<Enter>
```

Pressing F10 exits FilterView permanently. For applications where the same parameter settings will be used over and over again, for example in optimizing or debugging a filter, it is desirable to by-pass the lengthy process of selecting the options. FilterView makes sure that you do (or don't) save the current parameters into a setup-file before exiting FilterView by prompting:

```
Save current setup?
```

which has a default value of Y (yes).

If the parameters are to be saved, FilterView prompts for the filename:

```
Saving current setup  
Filename[.FVS] _____
```

where the filename extension defaults to .FVS if not otherwise specified by the user.

3.4 FilterView Limitations

Memory Requirements	256K
Number of frequency points	201
Number of displayed files	10
Number of variables per plot	15
Numeric range	-1e30 to =1e30

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SECTION 13 Design example #1.

This example is chosen to illustrate the use of all subprograms in the filter software package and to illustrate the implementation of a bandpass filter on three different device types.

The specs are as follows: Bandpass, center frequency 1000 Hz, bandwidth 600 Hz, stop bandwidth 2000 Hz, maximum ripple 1 dB, minimum attenuation at stop band 20 dB, gain at center frequency 1 V/V. The type chosen is Chebyshev.

The specs are analyzed using subprogram PZ which determines how many sections are needed, the locations of the poles, and the values of Q. At this point the design is worked out in three possible ways:

- (i) using the MAX265/266 which are programmed with resistors with the aid of subprogram RP. Next, commercial tolerance resistors are sub-

stituted for the ideal resistors and the effect of this is checked using RPCHECK.

- (ii) using the MAX260/261/262 μ P programmable parts with help of program MPP.

- (iii) using the MAX267/268 and the multiple feedback technique which applies to bandpass only. Here subprogram BP is used.

The answers from (i) and (ii) can be checked using program FR which will deliver frequency response data. This can be compared with the frequency response prediction from PZ.

In program PZ the GAF for the bandpass filter is worked out. This is the factor needed to set the gain for the stages to obtain the correct gain (unity in this case) for the system.

Keystroke input for PZ is:

/Chebyshev bandpass/b/c/2/1/1000/600/n/20/2000/n/y/1/0/4000/20/y/y/n/n

Output files of PZ are as follows.

Example 1

2/25/88 9:14 Chebyshev bandpass PZ<0.2>

FILTER TYPE: CHEBYSHEV BANDPASS

Specified Parameters:

Center Frequency is 1000.0000 Pass Bandwidth is 600.0000

Stop Bandwidth is 2000.0000

Amin=20.00 db Amax= 1.0000 db

Calculated Parameters:

Pass Band Low Edge is 744.0307 Pass Band High Edge is 1344.0307

Stop Band Low Edge is 414.2136 Stop Band High Edge is 2414.2136

Order= 4 N= 2 Actual Attenuation=20.70

Data for Lowpass Prototype, Normalized at 1 rad/sec:

FC=	1.0000FS=	3.3333
	Pole	Q
	1.0500	0.9565

Data for final design of CHEBYSHEV BANDPASS Filter

Quadratic Coefficients for Denormalized Gain Function in Rad/Sec

Numerator			Denominator		
s^2	s^1	s^0	s^2	s^1	s^0
0.0	1.526E+03	0.000E+00	1.0	1.526E+03	2.306E+07
0.0	2.612E+03	0.000E+00	1.0	2.612E+03	6.758E+07

Resonant Frequencies in Hertz:

Pole	Q
764.3366	3.1469
1308.3242	3.1469

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Special note on gain of bandpass:

Gain adjustment factor for bandpass = GAF = 3.930

For bandpass filters, the gain of the system at center frequency is given in terms of the gains of the individual stages by the expression:

Bandpass gain at center frequency = $H0_BP_1 \cdot H0_BP_2 \cdot \dots \cdot H0_BP_N / GAF$

The above individual stage gains are defined at the center frequency of each stage, which may be different from the center frequency of the overall system. The gain adjustment factor is used to arrive at the correct bandpass gain when defined at the overall system center frequency.

Example 1

2/25/88 9:14 Chebyshev bandpass

PZ<0.2>

Gain is normalized at 1000.0000, -1.0000 db

Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
0.000	*****	*****	*****
200.000	-35.209	172.052	1.22204E-04
400.000	-20.583	160.983	2.02752E-04
600.000	-8.207	136.521	5.82988E-04
800.000	0.982	56.739	1.28153E-03
1000.000	0.000	-0.000	5.28218E-04
1200.000	0.929	-42.619	7.41927E-04
1400.000	-1.235	-99.219	6.55696E-04
1600.000	-6.594	-130.770	2.73206E-04
1800.000	-11.033	-144.562	1.33557E-04
2000.000	-14.471	-151.936	7.86457E-05
2200.000	-17.239	-156.545	5.22080E-05
2400.000	-19.554	-159.728	3.74795E-05
2600.000	-21.544	-162.076	2.83981E-05
2800.000	-23.292	-163.890	2.23747E-05
3000.000	-24.854	-165.340	1.81558E-05
3200.000	-26.266	-166.531	1.50740E-05
3400.000	-27.556	-167.529	1.27467E-05
3600.000	-28.745	-168.379	1.09410E-05
3800.000	-29.849	-169.114	9.50856E-06
4000.000	-30.878	-169.755	8.35085E-06

The above two sections can be implemented with resistor programmed parts with the aid of program RP. Remember from PZ that we need to implement a gain of 3.93 to normalize the gain of the cascaded bandpass sections. We will take gain of unity in the first stage and all of the gain in the second stage.

Keystroke input to first run of RP: Chebyshev bandpass/2/5/3/3/100000/102/764.3366/3.1469/1/n

Example 1

2/25/88 9:17 Chebyshev bandpass

RP<0.2>

Bandpass using Mode 3

R1 =	81.2652	This group of resistors, expressed in K ohms, is scaled so that the smallest is 20.00K ohms. They may be rescaled to other reasonable values using a constant multiplying factor.
R2 =	20.0000	
R3 =	81.2652	
R4 =	33.1321	

Both clock frequency and clock ratio specified by user

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H0__LP =	-0.4077	
H0__HP =	-0.2461	
H0__BP =	-1.0000	
F0 =	764.3366	Target value
F0 =	760.9522	Target value after warp
F0 =	764.3366	Actual value achieved
Q =	3.1469	Target value
Q =	3.1569	Warped target value
Q =	3.1469	Actual value achieved
clk ratio=	102.0000	Specified value
clk ratio=	102.1018	Actual quantized value
clk freq=	100000.0000	
N=	1	0 0 0 0 0 1 are pin settings for clock ratio

(this code proper for parts with nominal ratio range of approx 100-200)

Keystroke input to second run of RP: Chebyshev bandpass
/2/5/3/3/100000/102/1308.3242/3.1469/3.93/n

Example 1

2/25/88 9:19 Chebyshev bandpass
Bandpass using Mode 3

RP<0.2>

R1 =	21.2882	This group of resistors, expressed in K ohms, is scaled so that the smallest is 20.00K ohms. They may be rescaled to other reasonable values using a constant multiplying factor.
R2 =	34.9594	
R3 =	83.6625	
R4 =	20.0000	

Both clock frequency and clock ratio specified by user

H0__LP =	-0.9395	
H0__HP =	-1.6422	
H0__BP =	-3.9300	
F0 =	1308.3242	Target value
F0 =	1294.8933	Target value after warp
F0 =	1308.3242	Actual value achieved
Q =	3.1469	Target value
Q =	3.1640	Warped target value
Q =	3.1469	Actual value achieved
clk ratio=	102.0000	Specified value
clk ratio=	102.1018	Actual quantized value
clk freq=	100000.0000	
N=	1	0 0 0 0 0 1 are pin settings for clock ratio

(this code proper for parts with nominal ratio range of approx 100-200)

The results above give ideal resistors. We use instead commercial values of resistors and plug them into RPCHECK with a resultant loss of precision as will be evident.

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Keystrokes to first run of RPCHECK: First section/2/3/100000/102/82.5/20

82.5/33.2/n

Example 1

2/25/88 9:20 First section

Check of Mode 3

RPCHECK<0.2>

R1 =	82.5000	
R2 =	20.0000	
R3 =	82.5000	
R4 =	33.2000	
H0 LP =	-0.4024	
H0 HP =	-0.2424	
H0 BP =	-1.0000	
F0=	763.5004	Value achieved
Q =	3.1916	Value achieved
clk ratio=	102.0000	value entered
clk ratio=	102.1018	value actually used
clk freq=	100000.0000	
N=	1	0 0 0 0 0 1 are pin settings for clock ratio

(this code proper for parts with nominal ratio range of approx 100-200)

Keystrokes to second run of RPCHECK: Second section/2/3/100000/102/21.5

/34.8/84.5/20/n

Example 1

2/25/88 9:22 Second section

Check of Mode 3

RPCHECK<0.2>

R1 =	21.5000
R2 =	34.8000
R3 =	84.5000
R4 =	20.0000

H0__LP =	-0.9302	
H0__HP =	-1.6186	
H0__BP =	-3.9302	
F0=	1304.8701	Value achieved
Q =	3.1861	Value achieved
clk ratio=	102.0000	value entered
clk ratio=	102.1018	value actually used
clk freq=	100000.0000	
N=	1	0 0 0 0 0 1 are pin settings for clock ratio

(this code proper for parts with nominal ratio range of approx 100-200)

As can be seen the center frequencies and Q's have changed due to the imprecision of the resistors. We will however press on and use these values from RPCHECK as the input to program FR which will calculate the frequency response of the two sections cascaded.

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Keystroke input to FR: Resistor programmed/2/1/b/n/763.5004/3.1916
/1/2/1/b/n/1304.8701/3.1861/3.9302/e/1/0/4000/20/y/1000/n/n/n

Example 1

2/25/88 9:23 Resistor programmed

FR<0.2>

(Section # 1) The order is 2
Not an Mode 3A section Gain set by resistors
Bandpass Pole frequency = 763.5004
Q = 3.1916
Zero (if not = 0)is 0.0000
Section gain factor is 1.0000

(Section # 2) The order is 2
Not an Mode 3A section Gain set by resistors
Bandpass Pole frequency = 1304.8701
Q = 3.1861
Zero (if not = 0) is 0.0000
Section gain factor is 3.9302

(Note: the following information on quadratic coefficients of S is for information only and is not required for the design.

Quadratic Coefficients for Denormalized Gain Function in Rad/Sec

Numerator			Denominator			Gain factor
s ²	s ¹	s ⁰	s ²	s ¹	s ⁰	
0.00E+00	1.50E+03	0.00E+00	1.00E+00	1.50E+03	2.30E+07	1.00E+00
0.00E+00	2.57E+03	0.00E+00	1.00E+00	2.57E+03	6.72E+07	3.93E+00

Gain is normalized at 1000.0000, -0.1342 db

Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
0.000	*****	*****	*****
200.000	-35.269	172.144	1.20828E-04
400.000	-20.629	161.190	2.00882E-04
600.000	-8.201	136.854	5.82832E-04
800.000	1.038	56.261	1.29095E-03
1000.000	0.000	-0.397	5.27018E-04
1200.000	0.969	-43.358	7.53926E-04
1400.000	-1.304	-100.500	6.52667E-04
1600.000	-6.732	-131.651	2.68133E-04
1800.000	-11.179	-145.176	1.30924E-04
2000.000	-14.616	-152.406	7.71440E-05
2200.000	-17.382	-156.929	5.12480E-05
2400.000	-19.694	-160.054	3.68120E-05
2600.000	-21.683	-162.360	2.79052E-05
2800.000	-23.430	-164.143	2.19943E-05
3000.000	-24.990	-165.569	1.78523E-05
3200.000	-26.401	-166.740	1.48254E-05
3400.000	-27.691	-167.722	1.25388E-05
3600.000	-28.879	-168.558	1.07642E-05
3800.000	-29.982	-169.281	9.35615E-06
4000.000	-31.011	-169.912	8.21789E-06

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Whether this frequency response is close enough to the ideal of PZ is a matter for the judgement of the designer. The differences are due to the imprecision of the resistors chosen. To verify this fact the user may wish to use the output of RP as the input of FR (instead of the output of RPCHECK used above) and the exact correspondence in response between FR and PZ will be seen.

Now we move on to the register programmable parts, where ratio and Q are quantized. We take the data from PZ and plug it into program MPP. Note on gain of bandpass: With pin programmable and register programmable parts, the gain is fixed internally. In the bandpass case the gain is equal to Q. Hence (referring to the output of PZ above) we would expect the overall gain of the two stages to be: $\text{gain} = Q1 \cdot Q2 / \text{GAF}$
 $= 3.1469 \cdot 3.1469 / 3.93 = 2.52$

This value will be expected when the output of MPP is checked with FR.

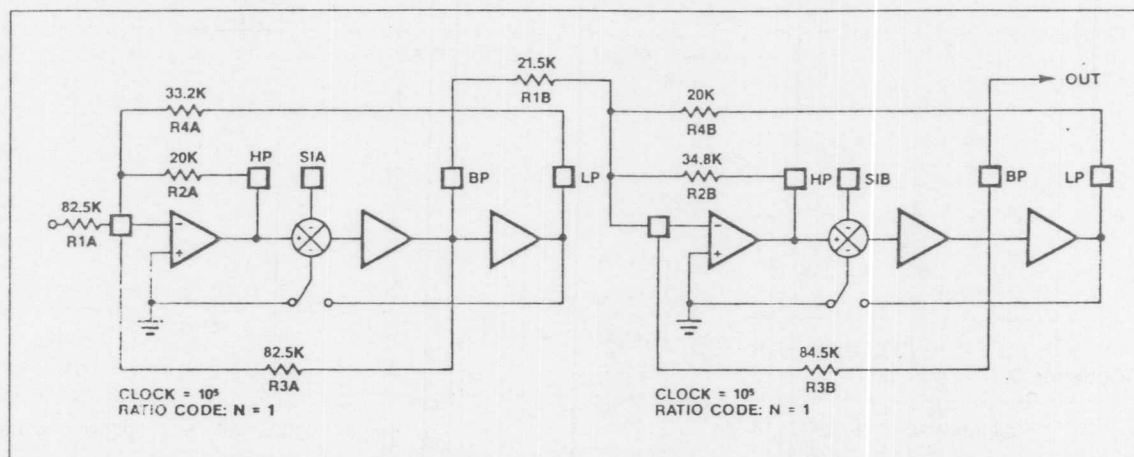


Figure 1. Resistor programming, mode 3

Keystroke input to MPP: Chebyshev bandpass, first section/2/6/1/2
 /764.3366/3.1469/1308.3242/3.1469/1/140000/140000/n

Example 1
 2/25/88 9:32 Chebyshev bandpass, first sect
 Maxim Program MPP: Calculations for Mode 1

MPP <0.2>

DATA INPUT FOR SECTION #1
 Specified center frequency, f0, is 764.3366
 Specified Q is 3.1469
 Specified clock frequency is 140000.0000

F0 CODE REQUIRED FOR SECTION #1
 Code for clock ratio: N = 53 = 1 1 0 1 0 1

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Q CODE REQUIRED FOR SECTION #1

Code for Q selection: N = 108 = 1 1 0 1 1 0 0

COMMENT ON SECTION #1

Above code applies to parts with a SIX BIT clock/center freq ratio code (code for parts with ratio range of 100-200, except mode 2 with 71-142)

Value of center frequency 'targeted' was 761.7672

Actual center frequency delivered by the circuit will be 765.4096

Clock ratio dialed in is 183.7832

The Q 'targeted' was 3.1476

Value of Q delivered by the circuit is 3.1993

Following are gains at filter terminals:

H0__LP = -1.0, H0__N1 = -1.0 (freq = 0 Hz), H0__N2 = -1.0 (freq = clk/2)

H0__BP = -Q = -3.1993

DATA INPUT FOR SECTION #2

Specified center frequency, f0, is 1308.3242

Specified Q is 3.1469

Specified clock frequency is 140000.0000

F0 CODE REQUIRED FOR SECTION #2

Code for clock ratio: N = 5 = 0 0 0 1 0 1

Q CODE REQUIRED FOR SECTION #2

Code for Q selection: N = 108 = 1 1 0 1 1 0 0

COMMENT ON SECTION #2

Above code applies to parts with a SIX BIT clock/center freq ratio code (code for parts with ratio range of 100-200, except mode 2 with 71-142)

Value of center frequency 'targeted' was 1291.6923

Actual center frequency delivered by the circuit will be 1299.7348

Clock ratio dialed in is 108.3849

The Q 'targeted' was 3.1577

Value of Q delivered by the circuit is 3.1891

Following are gains at filter terminals:

H0__LP = -1.0, H0__N1 = -1.0 (freq = 0 Hz), H0__N2 = -1.0 (freq = clk/2)

H0__BP = -Q = -3.1891

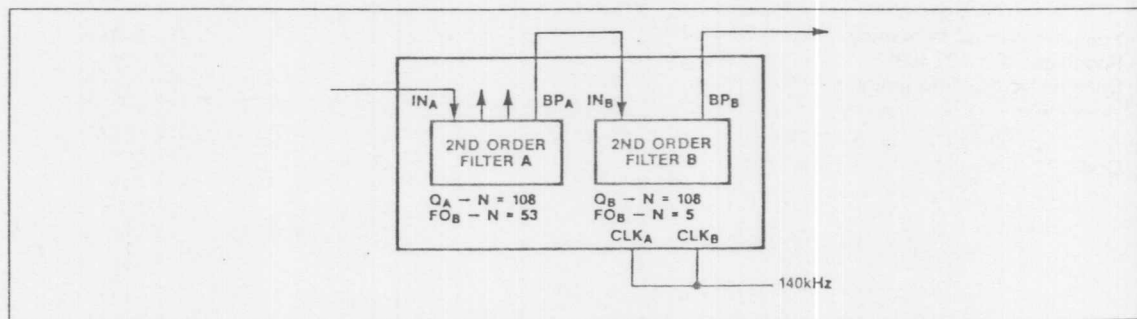


Figure 2. Cherbyshev bandpass filter using μP programmed devices. Mode 1 was used.

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Keystroke input to FR: Chebyshev bandpass, μP programmed/2/2/b/n/
765.4096/3.1993/3.1993/2/2/b/n/1299.7348/3.1891/3.1891/e/
1/0/4000/20/y/1000/n/n/n

Example 1

2/25/88 9:32 Chebyshev bandpass, μP programmed

FR<0.2>

(Section # 1) The order is 2
Not an Mode 3A section Gain set internally
Bandpass Pole frequency = 765.4096
Q = 3.1993
Zero (if not = 0) is 0.0000
Section gain factor is 3.1993

(Section # 2) The order is 2
Not an Mode 3A section Gain set internally
Bandpass Pole frequency = 1299.7348
Q = 3.1891
Zero (if not = 0) is 0.0000
Section gain factor is 3.1891

(Note: the following information on quadratic coefficients of S is for information only and is not required for the design.)

Quadratic Coefficients for Denormalized Gain Function in Rad/Sec

Numerator			Denominator			Gain factor
s ²	s ¹	s ⁰	s ²	s ¹	s ⁰	
0.00E+00	1.50E+03	0.00E+00	1.00E+00	1.50E+03	2.31E+07	3.20E+00
0.00E+00	2.56E+03	0.00E+00	1.00E+00	2.56E+03	6.67E+07	3.19E+00

Gain is normalized at 1000.0000, 8.2910 db

Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
0.000	*****	*****	*****
200.000	-35.426	172.161	1.20505E-04
400.000	-20.792	161.250	1.99786E-04
600.000	-8.377	137.138	5.75663E-04
800.000	0.996	56.942	1.30492E-03
1000.000	0.000	-0.580	5.35999E-04
1200.000	0.945	-44.411	7.68589E-04
1400.000	-1.510	-101.682	6.41968E-04
1600.000	-6.970	-132.196	2.62550E-04
1800.000	-11.404	-145.466	1.28799E-04
2000.000	-14.829	-152.591	7.61594E-05
2200.000	-17.588	-157.062	5.07114E-05
2400.000	-19.895	-160.156	3.64839E-05
2600.000	-21.879	-162.444	2.76873E-05
2800.000	-23.624	-164.213	2.18403E-05
3000.000	-25.182	-165.630	1.77382E-05
3200.000	-26.591	-166.794	1.47378E-05
3400.000	-27.880	-167.770	1.24694E-05
3600.000	-29.067	-168.602	1.07080E-05
3800.000	-30.169	-169.320	9.30960E-06
4000.000	-31.198	-169.949	8.17873E-06

Looking at the gain of the frequency response above, the offset due to normalizing is 8.291 dB or 2.59V/V of amplification. This is close to the gain predicted above. Since the digitally programmable parts do not have adjustable gain some other means such as an op amp are needed to scale the gain.

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The last method of achieving the same bandpass function uses the special bandpass parts MAX267/268 with resistors in the multiple feedback technique. In this case the output of PZ is not used. The basic specs of the filter are fed to program BP directly.

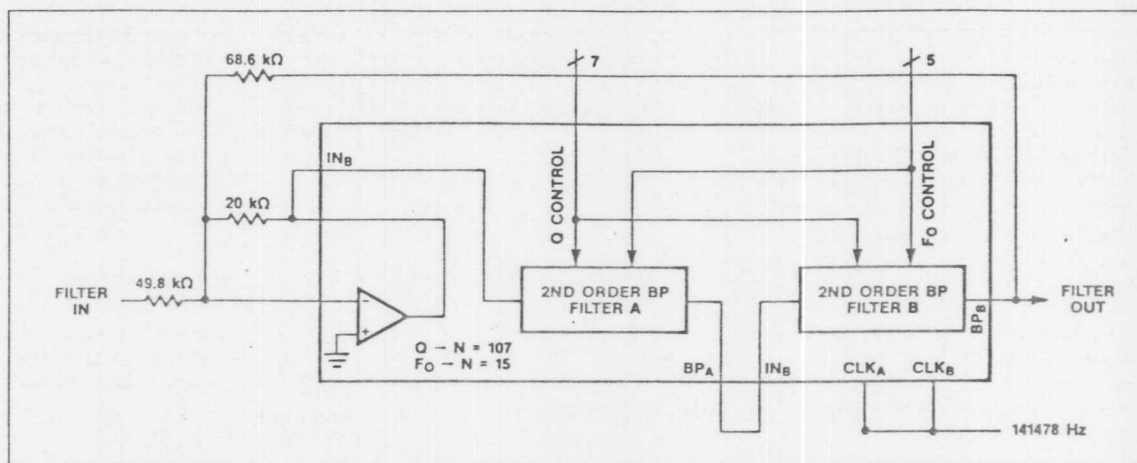


Figure 3. Bandpass filter implemented using MAX267. Multiple feedback techniques used. Both sections of the filter have identical F_0 & Q & clock frequency.

Keystroke input to BP: Chebyshev bandpass/2/1000/140000/c/4/1/600/1/n/n

Example 1

2/25/88 10:09 Chebyshev bandpass

BP<0.2>

Chebyshev Bandpass Filter of Order 4 using Multiple Feedback

Specified clock frequency 140000.0000 Hz

Center frequency specified 1000.0000 Hz

Actual center frequency achievable with this clock frequency 995.7731 Hz

Clock ratio used 141.3717

Specified maximum ripple 1.0000 db

Specified gain 1.0000 V/V

Bandwidth specified 600.0000 Hz

Actual achieved bandwidth 596.1399 Hz

*****Hint: to get closer to required bandwidth try varying the ripple. In general, higher ripple requires a higher Q. *****

Desired Q (for each second order section) 3.0365

Closest selectable Q is 3.0480 which results in actual Q 3.0432

RESISTOR SET

R2 = 34.8203 Kohm

R0 = 45.3066 Kohm

Rf = 10.0000 Kohm

Resistors are scaled so smallest
in group is 10.00 Kohm

CLOCK RATIO CODE

Code for clock ratio selection: N = 13 = 0 1 1 0 1

(this code proper for parts with nominal ratio range of approx 100-200)

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Q CODE

Code for Q selection: N = 107 = 1 1 0 1 0 1 1

***** Hint: for most exact center frequency, use a clock frequency of 140594.2712. Repeat program with this value. *****

The output above suggests a different clock frequency to achieve improved accuracy for the center frequency. We repeat the example using the suggestion.

Keystroke input to BP:Chebyshev bandpass/2/1000/140594
/c/4/1/600/1/nly/1/0/4000/20/n/n

Example 1

2/25/88 10:13 Chebyshev bandpass
Chebyshev Bandpass Filter of Order 4 using Multiple Feedback
Specified clock frequency 140594.0000 Hz
Center frequency specified 1000.0000 Hz
Actual center frequency achievable with this clock frequency 999.9981 Hz
Clock ratio used 141.3717
Specified maximum ripple 1.0000 db
Specified gain 1.0000 V/V
Bandwidth specified 600.0000 Hz
Actual achieved bandwidth 598.6693 Hz

BP<0.2>

***** Hint: to get closer to required bandwidth try varying the ripple. In general, higher ripple requires a higher Q. *****

Desired Q (for each second order section) 3.0365
Closest selectable Q is 3.0480 which results in actual Q 3.0432

RESISTOR SET

R2 =	34.8203 Kohm	
R0 =	25.3066 Kohm	Resistors are scaled so smallest
Rf =	10.0000 Kohm	in group is 10.00 Kohm

CLOCK RATIO CODE

Code for clock ratio selection: N = 13 = 0 1 1 0 1
(this code proper for parts with nominal ratio range of approx 100-200)

Q CODE

Code for Q selection: N = 107 = 1 1 0 1 0 1 1

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***** Hint: for most exact center frequency, use a clock frequency of 140594.2712. Repeat program with this value. *****

Example 1

2/25/88 10:13 Chebyshev bandpass

BP<0.2>

Gain not normalized

Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
0.000	*****	*****	*****
200.000	-35.247	172.069	1.21919E-04
400.000	-20.623	161.029	2.02172E-04
600.000	-8.247	136.651	5.80826E-04
800.000	0.981	56.916	1.28582E-03
1000.000	-0.000	-0.000	5.29381E-04
1200.000	0.930	-42.746	7.44703E-04
1400.000	-1.260	-99.454	6.54931E-04
1600.000	-6.633	-130.921	2.72209E-04
1800.000	-11.074	-144.663	1.33074E-04
2000.000	-14.511	-152.011	7.83828E-05
2200.000	-17.280	-156.605	5.20456E-05
2400.000	-19.594	-159.778	3.73694E-05
2600.000	-21.584	-162.119	2.83184E-05
2800.000	-23.332	-163.928	2.23141E-05
3000.000	-24.893	-165.375	1.81080E-05
3200.000	-26.305	-166.563	1.50352E-05
3400.000	-27.595	-167.558	1.27145E-05
3600.000	-28.784	-168.406	1.09138E-05
3800.000	-29.888	-169.138	9.48524E-06
4000.000	-30.917	-169.778	8.33059E-06

This completes the bandpass example demonstrated on three types of filter IC. The results can be observed on the graphics package FV. For instructions read the Tutorial section and the special section with all the details of FV. It will be appreciated that the files made so far with only 20 points are not sufficient to provide smooth graphic curves and were done that way to conserve space in this manual. The user can recreate these files using more points, say a minimum of 50 up to the maximum which the graphics can use which is 200. Use these keystrokes to get responses with 200 points:

(For PZ) Chebyshev bandpass/b/c/2/1/1000/600/n/20/2000/n/y/1/0/4000/200/y/y/n/n

(For FR) Resistor programmed/2/1/b/n/763.5004/3.1916/1/2/1/b/n/1304.8701/3.1861/3.9302/e/1/0/4000/200/y/1000/n/n/n

(For FR) Chebyshev bandpass, μ P programmed/2/2/b/n/765.4096/3.1993/3.1993/2/2/b/n/1299.7348/3.1891/3.1891/e/1/0/4000/200/y/1000/n/n/n

(For BP) Chebyshev bandpass/2/1000/140594/c/4/1/600/1/n/y/1/0/4000/200/n/n

Design example #2.

Specification:

Butterworth highpass filter, corner frequency 4000 Hz, stop frequency 2000 Hz, max ripple 2 dB, min attenuation 21 dB, gain 1. Clock is 450,000 Hz.

The steps followed in the example are:

1. Use PZ to specify the stages. Do a frequency response run.
2. Do a resistor programmed design using RP for two Mode 3 stages.
3. Perform a run of FR to analyze the two stages from RP to check the frequency response and compare it with that from PZ. (A useful exercise would be to repeat the run of FR using the output from RPCHECK to see the effect of imprecise resistors on the frequency response.)

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4. A design using μP programmable parts is done using MPP.
5. FR is used to check the frequency response of the design from MPP.

Keystroke input to PZ: Butterworth HP/h/b/2/4000/n/20/2000/n/y/1/0/5000/25/n/n/n

Example 2

2/25/88 17:45 Butterworth HP

PZ<0.2>

FILTER TYPE: BUTTERWORTH HIGHPASS

Specified Parameters:

Corner Freq= 4000.0000 Stop Freq= 2000.0000

Amax= 2.0000 db Amin= 20.00 db

Calculated Parameters:

Order, N= 4 Actual Attenuation= 21.78 db

Data for Lowpass Prototype, Normalized at 1 rad/sec:

FC= 1.0000 FS= 2.0000

Pole	Q
1.0687	0.5412
1.0687	1.3066

Data for final design of BUTTERWORTH HIGHPASS Filter

Quadratic Coefficients for Denormalized Gain Function in Rad/Sec

Numerator			Denominator		
s^2	s^1	s^0	s^2	s^1	s^0
1.0	0.000E+00	0.000E+00	1.0	4.345E+04	5.531E+08
1.0	0.000E+00	0.000E+00	1.0	1.800E+04	5.531E+08

Resonant Frequencies in Hertz:

Pole	Q
3742.8495	0.5412
3742.8495	1.3066

Example 2

2/25/88 17:45 Butterworth HP

PZ<0.2>

Gain not normalized

Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
0.000	*****	*****	*****
200.000	-101.766	-8.004	1.11248E-04
400.000	-77.684	-16.026	1.11648E-04
600.000	-63.596	-24.088	1.12331E-04
800.000	-53.601	-32.209	1.13325E-04
1000.000	-45.849	-40.415	1.14674E-04
1200.000	-39.515	-48.732	1.16441E-04
1400.000	-34.160	-57.195	1.18716E-04
1600.000	-29.524	-65.842	1.21607E-04
1800.000	-25.439	-74.724	1.25240E-04
2000.000	-21.795	-83.897	1.29735E-04
2200.000	-18.516	-93.428	1.35169E-04
2400.000	-15.554	-103.384	1.41501E-04
2600.000	-12.880	-113.820	1.48478E-04
2800.000	-10.482	-124.766	1.55512E-04
3000.000	-8.362	-136.192	1.61615E-04
3200.000	-6.527	-147.985	1.65501E-04

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Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
0.000	*****	*****	*****
3400.000	-4.985	-159.941	1.65934E-04
3600.000	-3.731	-171.780	1.62233E-04
3800.000	-2.747	176.793	1.54613E-04
4000.000	-2.000	166.026	1.44088E-04
4200.000	-1.447	156.081	1.32013E-04
4400.000	-1.045	147.023	1.19612E-04
4600.000	-0.756	138.844	1.07742E-04
4800.000	-0.549	131.484	9.68703E-05
5000.000	-0.401	124.866	8.71758E-05

The two stages specified above by PZ are now designed using Mode 3 with the help of RP.

Keystroke input to first run of RP: Butterworth HP section 1/2/4/3/3/
450000/101/3742.8495/1.5412/1

Example 2

2/25/88 17:49 Butterworth HP section 1
Highpass second order using Mode 3

RP<0.2>

R1 = 29.1696 This group of resistors, expressed in K ohms,
R2 = 29.1696 is scaled so that the smallest is 20.00K ohms.
R3 = 20.0000 They may be rescaled to other reasonable values
R4 = 45.4544 using a constant multiplying factor.
Both clock frequency and clock ratio specified by user

H0__LP = -1.5583
H0__HP = -1.0000
H0__BP = -0.6856
F0 = 3742.8495 Target value
F0 = 3585.8294 Target value after warp
F0 = 3742.8495 Actual value achieved
Q = 0.5412 Target value
Q = 0.5493 Warped target value
Q = 0.5412 Actual value achieved
clk ratio= 101.0000 Specified value
clk ratio= 100.5310 Actual quantized value
clk freq= 450000.0000
N= 0 0 0 0 0 0 are pin settings for clock ratio
(this code proper for parts with nominal ratio range of approx 100-200)

Keystroke input to second run of RP: Butterworth HP second section/
2/4/3/3/450000/101/3742.8495/1.3066/1

Example 2

2/25/88 17:51 Butterworth HP second section
Highpass second order using Mode 3

RP<0.2>

R1 = 20.0000 This group of resistors, expressed in K ohms,
R2 = 20.0000 is scaled so that the smallest is 20.00K ohms.
R3 = 32.0388 They may be rescaled to other reasonable values
R4 = 29.6164 using a constant multiplying factor.
Both clock frequency and clock ratio specified by user

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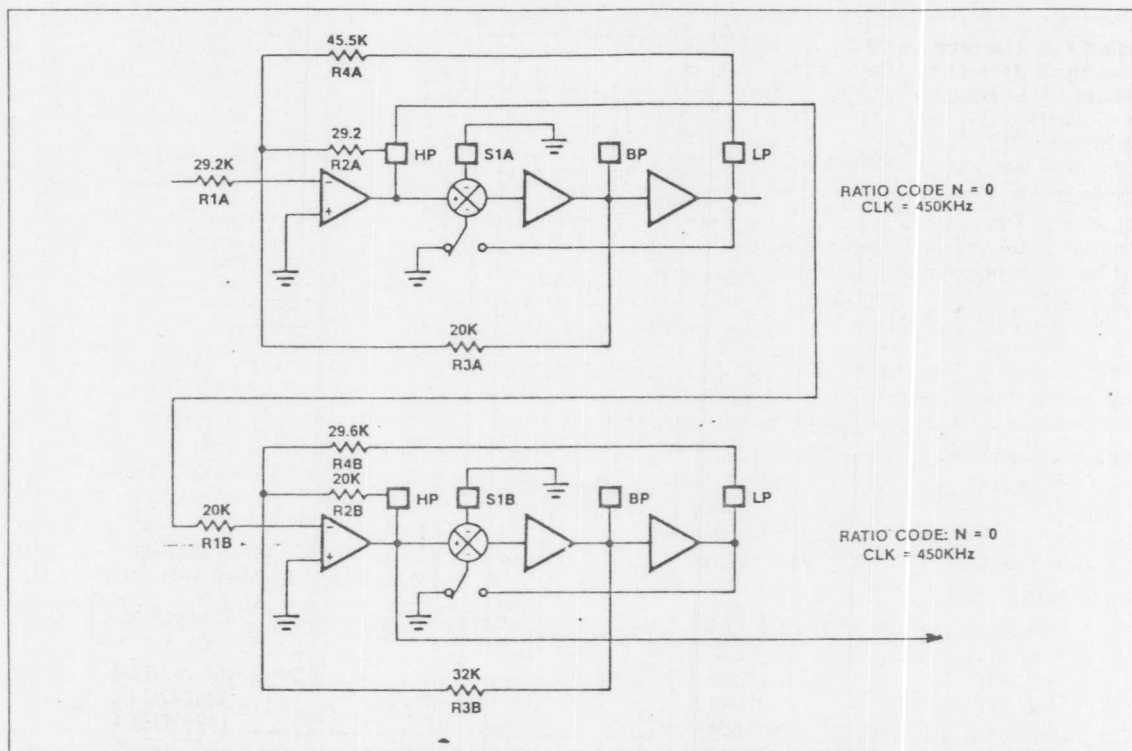


Figure 4. Implementation of a high pass filter with resistor programming devices.

H0__LP =	-1.4808	
H0__HP =	-1.0000	
H0__BP =	-1.6019	
F0 =	3742.8495	Target value
F0 =	3678.4204	Target value after warp
F0 =	3742.8495	Actual value achieved
Q =	1.3066	Target value
Q =	1.3164	Warped target value
Q =	1.3066	Actual value achieved
clk ratio=	101.0000	Specified value
clk ratio=	100.5310	Actual quantized value
clk freq=	450000.0000	
N=	0	0 0 0 0 0 are pin settings for clock ratio

(this code proper for parts with nominal ratio range of approx 100-200)

The two cascaded sections from RP are now checked for frequency response using FR. Keystroke input to FR:
Butterworth P/2/1/h/n/3742.8495/.5412
1/2/1/h/n/3742.8495/1.3066/1/e/1/0/5000/1/25/n/n

Example 2

2/25/88 17:51 Butterworth HP

FR<0.2>

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(Section # 1) The order is 2
 Not an Mode 3A section Gain set by resistors
 Highpass Pole frequency = 3742.8495
 Q = 0.5412
 Zero (if not = 0) is 0.0000
 Section gain factor is 1.0000

(Section # 2) The order is 2
 Not an Mode 3A section Gain set by resistors
 Highpass Pole frequency = 3742.8495
 Q = 1.3066
 Zero (if not = 0) is 0.0000
 Section gain factor is 1.0000

(Note: the following information on quadratic coefficients of S is for information only and is not required for the design.)

Quadratic Coefficients for Denormalized Gain Function in Rad/Sec

Numerator				Denominator		Gain factor
s ²	s ¹	s ⁰	s ²	s ¹	s ⁰	
1.00E+00	0.00E+00	0.00E+00	1.00E+00	4.35E+04	5.53E+08	1.00E+00
1.00E+00	0.00E+00	0.00E+00	1.00E+00	1.80E+04	5.53E+08	1.00E+00

Gain not normalized

Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
0.000	*****	*****	*****
200.000	-101.774	-8.003	1.11247E-04
400.000	-77.691	-16.026	1.11647E-04
600.000	-63.604	-24.087	1.12330E-04
800.000	-53.609	-32.209	1.13324E-04
1000.000	-45.856	-40.414	1.14673E-04
1200.000	-39.522	-48.732	1.16440E-04
1400.000	-34.168	-57.194	1.18715E-04
1600.000	-29.531	-65.841	1.21606E-04
1800.000	-25.447	-74.723	1.25239E-04
2000.000	-21.802	-83.897	1.29734E-04
2200.000	-18.524	-93.427	1.35168E-04
2400.000	-15.562	-103.383	1.41501E-04
2600.000	-12.887	-113.819	1.48479E-04
2800.000	-10.490	-124.765	1.55513E-04
3000.000	-8.369	-136.191	1.61617E-04
3200.000	-6.535	-147.985	1.65504E-04
3400.000	-4.992	-159.940	1.65937E-04
3600.000	-3.738	-171.780	1.62236E-04
3800.000	-2.755	176.792	1.54617E-04
4000.000	-2.007	166.026	1.44091E-04
4200.000	-1.454	156.080	1.32015E-04
4400.000	-1.052	147.023	1.19614E-04
4600.000	-0.763	138.843	1.07743E-04
4800.000	-0.556	131.484	9.68712E-05
5000.000	-0.408	124.865	8.71764E-05

The above frequency response can be compared with the response predicted in PZ. The same filter is now designed with μP or filters using program MPP in Mode 3, using one run for both stages. If desired each stage could be done in a separate run.

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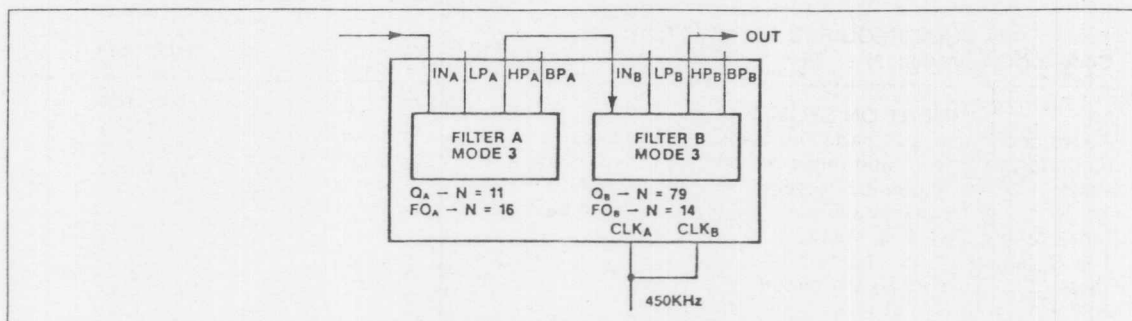


Figure 5. 4th Order highpass filter implemented with μP or pin programmed devices.

Keystroke input to MPP: Butterworth HP/2/6/3/2/3742.8495/.5412/
3742.8495/1.3066/1/450000/450000

Example 2

2/25/88 18:01 Butterworth HP

Maxim Program MPP: Calculations for Mode 3

MPP<0.2>

DATA INPUT FOR SECTION #1

Specified center frequency, f_0 , is 3742.8495

Specified Q is 0.5412

Specified clock frequency is 450000.0000

F0 CODE REQUIRED FOR SECTION #1

Code for clock ratio: $N = 16 = 010000$

Q CODE REQUIRED FOR SECTION #1

Code for Q selection: $N = 11 = 0001011$

COMMENT ON SECTION #1

Above code applies to parts with a SIX BIT clock/center freq ratio code
(code for parts with ratio range of 100-200, except mode 2 with 71-142)

Value of center frequency 'targeted' was 3580.9862

Actual center frequency delivered by the circuit will be 3740.5157

Clock ratio dialed in is 125.6637

The Q 'targeted' was 0.5481

Value of Q delivered by the circuit is 0.5401

Following are gains at filter terminals:

$H_0_LP = -1.0$, $H_0_HP = -1.0$, $H_0_BP = -Q = -0.5401$ (freq = f_0)

DATA INPUT FOR SECTION #2

Specified center frequency, f_0 , is 3742.8495

Specified Q is 1.3066

Specified clock frequency is 450000.0000

F0 CODE REQUIRED FOR SECTION #2

Code for clock ratio: $N = 14 = 001110$

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Q CODE REQUIRED FOR SECTION #2

Code for Q selection: N = 79 = 1 0 0 1 1 1 1

COMMENT ON SECTION #2

Above code applies to parts with a SIX BIT clock/center freq ratio code

(code for parts with ratio range of 100-200, except mode 2 with 71-142)

Value of center frequency 'targeted' was 3672.8064

Actual center frequency delivered by the circuit will be 3735.0429

Clock ratio dialed in is 122.5221

The Q 'targeted' was 1.3144

Value of Q delivered by the circuit is 1.2982

Following are gains at filter terminals:

H0__LP = -1.0, H0__HP = -1.0, H0__BP = -Q = -1.2982 (freq = f0)

The design above from MPP is now fed into FR to give the frequency response for the two stages cascaded.

Keystroke input to FR: Butterworth HP/2/2/h/n/3740.5157/.5401/1/2/2/h/n

/3735.0429/1.2982/1/e/1/0/5000/25/n/n/n

Example 2

2/25/88 18:02 Butterworth HP

FR<0.2>

(Section # 1) The order is 2

Not an Mode 3A section Gain set internally

Highpass Pole frequency = 3740.5157

Q = 0.5401

Zero (if not = 0) is 0.0000

Section gain factor is 1.0000

(Section # 2) The order is 2

Not an Mode 3A section Gain set internally

Highpass Pole frequency = 3735.0429

Q = 1.2982

Zero (if not = 0) is 0.0000

Section gain factor is 1.0000

(Note: the following information on quadratic coefficients of S is for information only and is not required for the design.)

Quadratic Coefficients for Denormalized Gain Function in Rad/Sec

s^2	Numerator s^1	s^0	s^2	Denominator s^1	s^0	Gain factor
1.00E+00	0.00E+00	0.00E+00	1.00E+00	4.35E+04	5.52E+08	1.00E+00
1.00E+00	0.00E+00	0.00E+00	1.00E+00	1.81E+04	5.51E+08	1.00E+00

Gain not normalized

Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
0.000	*****	*****	*****
200.000	-101.727	-8.039	1.11734E-04
400.000	-77.645	-16.096	1.12130E-04
600.000	-63.559	-24.192	1.12807E-04
800.000	-53.565	-32.348	1.13795E-04
1000.000	-45.814	-40.587	1.15138E-04
1200.000	-39.483	-48.938	1.16901E-04
1400.000	-34.131	-57.433	1.19174E-04
1600.000	-29.498	-66.114	1.22066E-04

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Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
0.000	*****	*****	*****
1800.000	-25.416	-75.028	1.25702E-04
2000.000	-21.777	-84.235	1.30199E-04
2200.000	-18.503	-93.799	1.35624E-04
2400.000	-15.547	-103.786	1.41926E-04
2600.000	-12.881	-114.252	1.48833E-04
2800.000	-10.492	-125.219	1.55740E-04
3000.000	-8.382	-136.654	1.61649E-04
3200.000	-6.559	-148.442	1.65286E-04
3400.000	-5.027	-160.372	1.65455E-04
3600.000	-3.783	-172.168	1.61532E-04
3800.000	-2.807	176.460	1.53778E-04
4000.000	-2.064	165.755	1.43218E-04
4200.000	-1.513	155.872	1.31188E-04
4400.000	-1.111	146.871	1.18880E-04
4600.000	-0.821	138.740	1.07120E-04
4800.000	-0.612	131.421	9.63564E-05
5000.000	-0.461	124.836	8.67583E-05

The frequency response data can be compared with the predicted performance in PZ above.

NOTE ON ORDER OF STAGES IN CIRCUIT IMPLEMENTATION

The order in which the stages are placed does not affect the frequency response. However when large signals are expected and clipping may be a problem then the low Q section should be placed first as in these examples. If noise is of primary concern however it is better to place the high Q section first.

Design example #3.

Specification:

Elliptic bandpass, $f_0=1000$ Hz, bandwidth=500, stopband width =750 Hz, maximum ripple=.5 dB, minimum attenuation = 20 dB, gain at 1000 Hz =1.

Steps in example:

- (1) analyze problem with PZ
- (2) design 3 stages with RP for resistor programmed parts
- (3) check design with FR
- (4) modify design to delete op amps
- (5) design 3 stages with MPP for μP programmable parts
- (6) check design with FR

SETTING GAIN OF BANDPASS FILTERS

The gain of the bandpass is set using the GAF (gain adjustment factor) which comes out of program PZ and is used with RP and MPP to produce the proper gain coefficients in the individual stages.

Keystrokes for PZ: Elliptic BP/b/e/2/.5/1000/500/n/20/750/n/y/
1/0/2000/20/y/y/n/n

Example 3

2/25/88 18:08 Elliptic BP

PZ<0.2>

FILTER TYPE: ELLIPTIC BANDPASS

Specified Parameters:

Center Frequency is 1000.0000 Pass Bandwidth is 500.0000
Stop Bandwidth is 750.0000
Amin=20.00 db Amax= 0.5000 db

Calculated Parameters:

Pass Band Low Edge is 780.7764 Pass Band High Edge is 1280.7764
Stop Band Low Edge is 693.0005 Stop Band High Edge is 1443.0005
Order= 6 N= 3 Actual Attenuation=21.92

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Data for Lowpass Prototype, Normalized at 1 rad/sec:

FC=	1.0000FS=	1.5000
	Pole	Q
	1.0720	2.3672
0.7670	Zero	
	1.6751	

Data for final design of ELLIPTIC BANDPASS Filter

Quadratic Coefficients for Denormalized Gain Function in Rad/Sec

s^2	Numerator s^1	s^0	s^2	Denominator s^1	s^0
1.0	0.000E+00	1.748E+07	1.0	5.308E+02	2.350E+07
1.0	0.000E+00	8.917E+07	1.0	8.919E+02	6.633E+07
0.0	2.409E+03	0.000E+00	1.0	2.409E+03	3.948E+07

Resonant Frequencies in Hertz:

Pole	Q
771.4947	9.1317
1296.1851	9.1317
1000.0000	2.6077
Zero	
665.3685	
1502.9266	

Special note on gain of bandpass:

Gain adjustment factor for bandpass = GAF = 3.014

In case of bandpass filters the gain of the system is given by the expression:

Bandpass gain at center frequency = $H0_BP_1 \cdot H0_BP_2 \cdot \dots \cdot H0_BP_N / GAF$

where these individual stage gains are defined at the center frequencies of each stage (not the center frequency of the overall filter). The gain adjustment factor is used in the formula to arrive at the correct gain when defined at the center frequency of the overall bandpass function.

Example 3

2/25/88 18:08 Elliptic BP

PZ<0.2>

Gain is normalized at 1000.0000, 0.0000 db

Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
0.000	*****	*****	*****
100.000	-36.038	86.468	1.00245E-04
200.000	-29.901	82.697	1.10561E-04
300.000	-26.226	78.389	1.30883E-04
400.000	-23.643	73.072	1.68356E-04
500.000	-22.063	65.842	2.42536E-04
600.000	-23.303	54.372	4.27654E-04
700.000	-19.118	28.126	1.30997E-03
800.000	-0.001	-80.203	3.02142E-03
900.000	-0.421	-140.025	1.14838E-03
1000.000	0.000	-180.000	1.08094E-03
1100.000	-0.374	143.757	9.36349E-04
1200.000	-0.310	107.774	1.21855E-03

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Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
0.000	*****	*****	*****
1300.000	-1.547	38.504	2.48147E-03
1400.000	-14.302	-20.458	8.65492E-04
1500.000	-51.395	-40.425	3.58530E-04
1600.000	-25.447	-50.122	2.04251E-04
1700.000	-22.767	-56.109	1.36091E-04
1800.000	-22.042	-60.281	9.89343E-05
1900.000	-21.927	-63.399	7.59925E-05
2000.000	-22.063	-65.842	6.06341E-05

Note that the GAF is given by PZ, GAF=3.014. This means that to achieve an overall gain of 1 the products of the gains of the three stages must be 3.014. (See the manual section for PZ). We will use two 3A sections with gains of 0.1 and 3.014 and a final Mode 3 stage with a gain of 10.

Keystroke input to first run of RP: First section/2/5/3a/3/100000/101
/771.4947/9.1317/1/1/665.3685/3/1

Example 3

2/25/88 18:11 First section
Bandpass using Mode 3A

RP<0:2>

R1 =	333.0639	This group of resistors, expressed in K ohms, is scaled so that the smallest is 20.00K ohms. They may be rescaled to other reasonable values using a constant multiplying factor.
R2 =	20.0000	
R3 =	235.9506	
R4 =	33.3064	

Both clock ratio and clock frequency specified by user

RG =	20.0000	This group of resistors may be rescaled to other reasonable values using a constant multiplying factor.
RH =	28.1285	
RL =	62.9776	

H0__LP =	-0.1000	(intermediate node)
H0__HP =	-0.0600	(intermediate node)
H0__BP =	-0.7084	(intermediate node)
H0__ωN =	0.1000	= gain for F=F0, out of op amp
H0__N__1 =	0.0318	= gain as F tends to zero Hertz, out of op amp
H0__N__2 =	0.0427	= gain for F=F__CLK/2, out of op amp
F0 =	771.4947	Target value
F0 =	770.8172	Value after warp
F0 =	771.4947	Actual value achieved
FN =	665.3685	
Q =	9.1317	Target value
Q =	9.1420	Value after warp
Q =	9.1317	Actual achieved value
clk ratio=	101.0000	Specified value
clk ratio=	100.5310	Actual quantized value
clkfreq=	100000.0000	
N=	0	0 0 0 0 0 are pin settings for clock ratio

(this code proper for parts with nominal ratio range of approx 100-200)

6.5

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Keystroke input to second run of RP: Second section/2/5/3a/3/100000/101
/1296.1851/9.1317/2/3.014/1502.9266/3/3.014

Example 3
2/25/88 18:13 Second section
Bandpass using Mode 3A

RP<0.2>

R1 =	20.0000	This group of resistors, expressed in K ohms, is scaled so that the smallest is 20.00K ohms. They may be rescaled to other reasonable values using a constant multiplying factor.
R2 =	60.2800	
R3 =	424.4119	
R4 =	35.6763	

Both clock ratio and clock frequency specified by user

RG =	20.0000	This group of resistors may be rescaled to other reasonable values using a constant multiplying factor.
RH =	63.0456	
RL =	27.7537	

H0__LP =	-1.7838	(intermediate node)
H0__HP =	-3.0140	(intermediate node)
H0__BP =	-21.2206	(intermediate node)
H0__N =	3.0140	= gain for F=F0, out of op amp
H0__N__1 =	1.2855	= gain as F tends to zero Hertz, out of op amp
H0__N__2 =	0.9561	= gain for F=F__CLK/2, out of op amp
F0 =	1296.1851	Target value
F0 =	1292.9944	Value after warp
F0 =	1296.1851	Actual value achieved
FN =	1502.9266	
Q =	9.1317	Target value
Q =	9.1519	Value after warp
Q =	9.1317	Actual achieved value
clk ratio=	101.0000	Specified value
clk ratio=	100.5310	Actual quantized value
clkfreq=	100000.0000	
N=	0	0 0 0 0 0 are pin settings for clock ratio

(this code proper for parts with nominal ratio range of approx 100-200)

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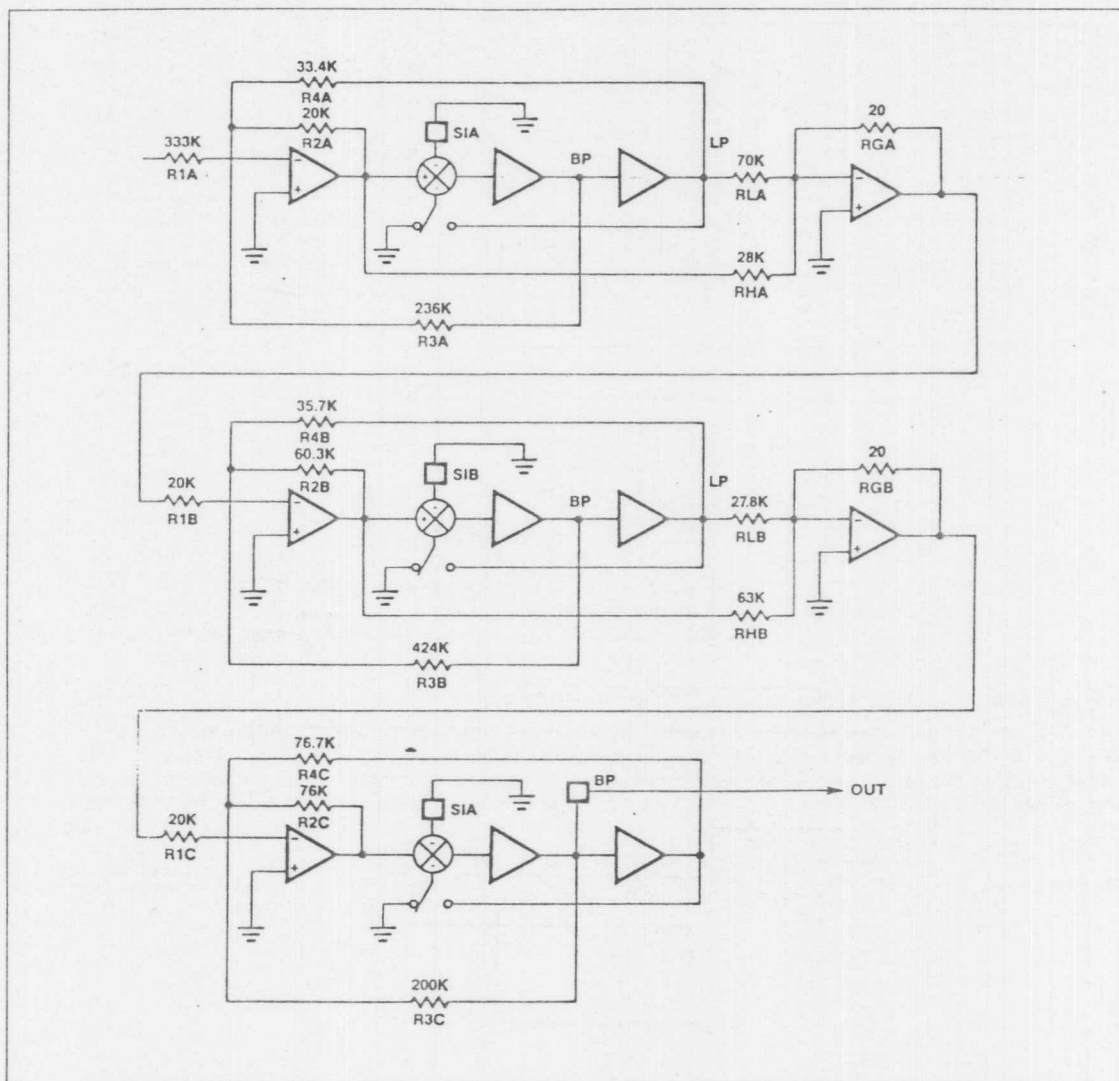


Figure 6. Example #3 with resistor programming implements elliptic bandpass filter.
Figure 6a. Before simplification. Mode 3A is used.

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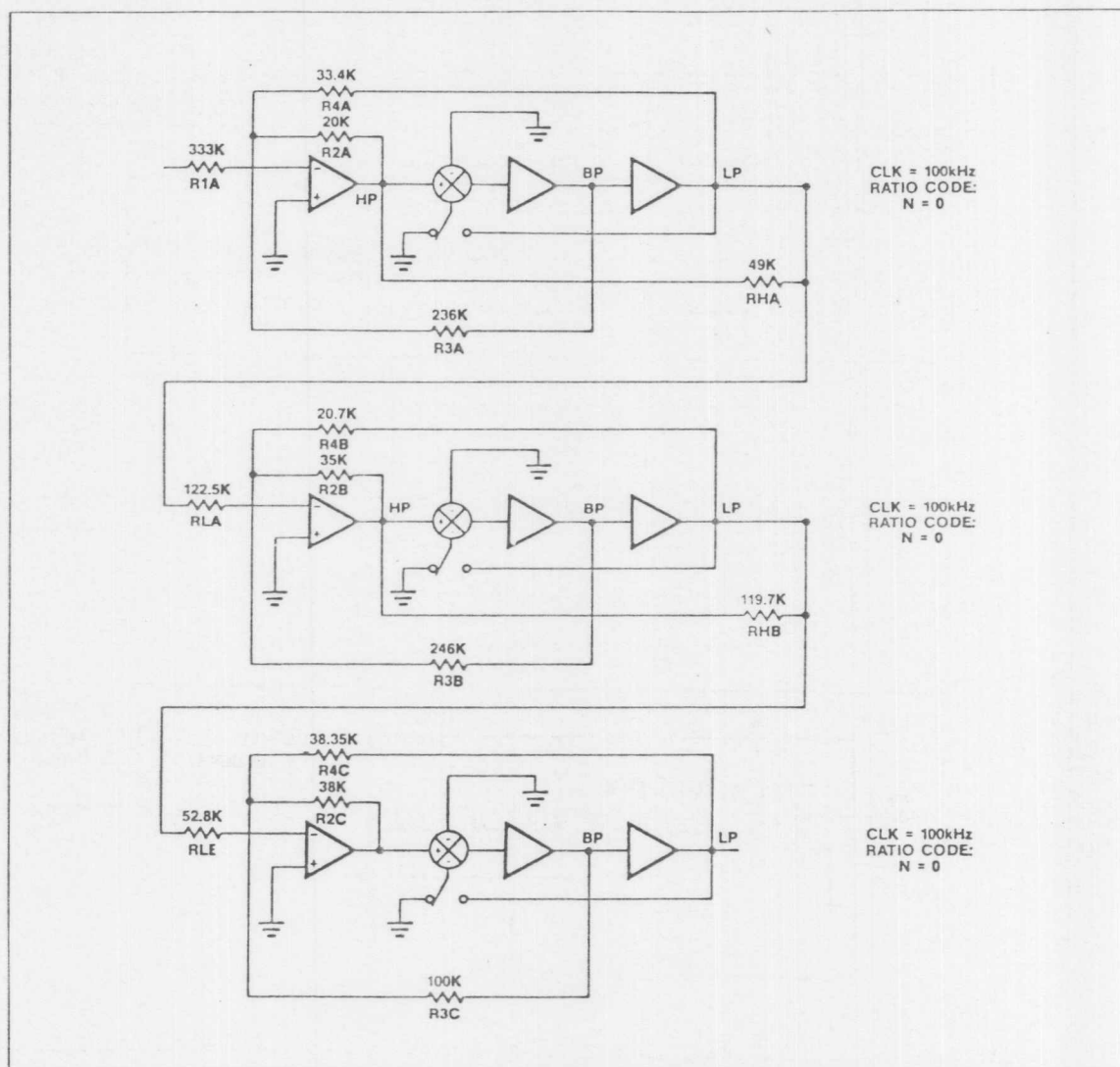


Figure 6b. After simplification, Mode 3A is used.

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Keystroke input to third run of RP: Third section/2/5/3/3/100000/101
/1000/2.6077/10

Example 3

2/25/88 18:16 Third section
Bandpass using Mode 3

RP<0.2>

R1 =	20.0000	This group of resistors, expressed in K ohms, is scaled so that the smallest is 20.00K ohms. They may be rescaled to other reasonable values using a constant multiplying factor.
R2 =	76.0181	
R3 =	200.0000	
R4 =	76.5987	

Both clock frequency and clock ratio specified by user

H0__LP =	-3.8299	
H0__HP =	-3.8009	
H0__BP =	-10.0000	
F0 =	1000.0000	Target value
F0 =	990.9415	Target value after warp
F0 =	1000.0000	Actual value achieved
Q =	2.6077	Target value
Q =	2.6210	Warped target value
Q =	2.6077	Actual value achieve
clk ratio=	101.0000	Specified value
clk ratio=	100.5310	Actual quantized value
clk freq=	100000.0000	
N=	0	0 0 0 0 0 are pin settings for clock ratio

(this code proper for parts with nominal ratio range of approx 100-200)

Simplification of Circuit by Elimination of the Op Amps

The analysis above assumes external op amps to create the zeros in the first two stages. In practice the input amplifier of the next stage performs this function and R2 of that stage performs the function of RG. With this in mind the RG for the two stages are replaced with the R2 of the next stage. The resistors are rescaled to retain the same ratios so that the filter functions are unchanged. The following two columns show the values before and after the simplification.

	BEFORE	AFTER	SCALE FACTOR
R1A	333	333	1
R2A	20	20	1
R3A	236	236	1
R4A	33.4	33.4	1
RGA	20	R2B=35	1.75
RHA	28	49	1.75
RLA	70	122.5	1.75
R1B	20	DELETE	
R2B	60.3	35	.58
R3B	424	246	.58
R4B	35.7	20.7	.58
RGB	20	R2C=38	1.9
RHB	63	119.7	1.9
RLB	27.8	52.8	1.9

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R1C	20	DELETE	
R2C	76	38	.5
R3C	200	100	.5
R4C	76.7	38.35	.5

The overall response for the three stages will now be checked with FR using the values from RP.
Keystroke input to FR:

Elliptic BP/2/1/b/y/771.4947/9.1317/20/28.1285/62.9776/1/.06
/2/1/b/y/1296.1851/9.1317/20/63.0456/27.7537/1.7838/3.014
/2/1/b/n/1000/2.6077/10/e/1/0/2000/20/y/1000/n/n

Example 3

2/25/88 18:17 Elliptic BP

FR<0.2>

(Section # 1) The order is 2

This is a Mode 3A section Gain set by resistors

Bandpass Pole frequency = 771.4947

Q = 9.1317

Zero (if not = 0) is 0.0000

RG = 20.0000 RH = 28.1285 RL = 62.9776

H0__LP = 0.1000 H0__HP = 0.0600

Section gain factor is 1.0000

(Section # 2) The order is 2

This is a Mode 3A section Gain set by resistors

Bandpass Pole frequency = 1296.1851

Q = 9.1317

Zero (if not = 0) is 0.0000

RG = 20.0000 RH = 63.0456 RL = 27.7537

H0__LP = 1.7838 H0__HP = 3.0140

Section gain factor is 1.0000

(Section # 3) The order is 2

Not an Mode 3A section Gain set by resistors

Bandpass Pole frequency = 1000.0000

Q = 2.6077

Zero (if not = 0) is 0.0000

Section gain factor is 10.0000

(Note: the following information on quadratic coefficients of S is for information only and is not required for the design.)

Quadratic Coefficients for Denormalized Gain Function in Rad/Sec

Numerator			Denominator			Gain factor
s^2	s^1	s^0	s^2	s^1	s^0	
4.27E-02	0.00E+00	7.46E+05	1.00E+00	5.31E+02	2.35E+07	1.00E+00
9.56E-01	0.00E+00	8.53E+07	1.00E+00	8.92E+02	6.63E+07	1.00E+00
0.00E+00	2.41E+03	0.00E+00	1.00E+00	2.41E+03	3.95E+07	1.00E+01

Gain is normalized at 1000.0000, -0.0406 db

Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
0.000	*****	*****	*****
100.000	-36.025	86.468	1.00246E-04
200.000	-29.888	82.697	1.10561E-04
300.000	-26.211	78.389	1.30884E-04

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Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
0.000	*****	*****	*****
400.000	-23.627	73.072	1.68357E-04
500.000	-22.041	65.842	2.42538E-04
600.000	-23.260	54.372	4.27656E-04
700.000	-19.178	28.125	1.30998E-03
800.000	-0.011	-80.203	3.02142E-03
900.000	-0.424	-140.025	1.14838E-03
1000.000	0.000	180.000	1.08093E-03
1100.000	-0.372	143.757	9.36346E-04
1200.000	-0.307	107.774	1.21855E-03
1300.000	-1.544	38.505	2.48147E-03
1400.000	-14.299	-20.458	8.65493E-04
1500.000	-51.415	-40.424	3.58531E-04
1600.000	-25.442	-50.121	2.04252E-04
1700.000	-22.762	-56.109	1.36091E-04
1800.000	-22.037	-60.280	9.89348E-05
1900.000	-21.922	-63.399	7.59929E-05
2000.000	-22.058	-65.842	6.06345E-05

Gain setting using MPP

The GAF from PZ is 3.014 so to get unity gain the products of the three section gains must be 3.014. There will be two mode 3A sections since there are two zeros and one mode 3 section. The latter has a gain of Q which is 2.6077. So the other two stages need an overall gain of $3.014/2.6077=1.156$. We will set the gain of the first stage at 1 and the second at 1.156.

Keystroke input to first run of MPP: Elliptic bandpass/2/6/3a/2/
768.3342/9.1317/665.3685/3/1/1296.1851/9.1317/1502.9266/3/1.156/1/
140000/140000

Example 3

2/25/88 18.26 Elliptic bandpass

MPP<0.2>

Maxim Program MPP: Calculations for Mode 3A

DATA INPUT FOR SECTION #1

Specified center frequency, f0, is 768.3342

Specified Q is 9.1317

Specified clock frequency is 140000.0000

F0 CODE REQUIRED FOR SECTION #1

Code for clock ratio: N = 52 = 1 1 0 1 0 0

Q CODE REQUIRED FOR SECTION #1

Code for Q selection: N = 121 = 1 1 1 1 0 0 1

COMMENT ON SECTION #1

Above code applies to parts with a SIX BIT clock/center freq ratio code
(code for parts with ratio range of 100-200, except mode 2 with 71-142)

Value of center frequency 'targeted' was 768.3342

Actual center frequency delivered by the circuit will be 769.2678

Clock ratio dialed in is 182.2124

The Q 'targeted' was 9.1317

Value of Q delivered by the circuit is 9.1430

Following are gains at filter terminals:

H0__LP = -1.0, H0__HP = -1.0, H0__BP = -Q = -9.1430 (freq = f0)

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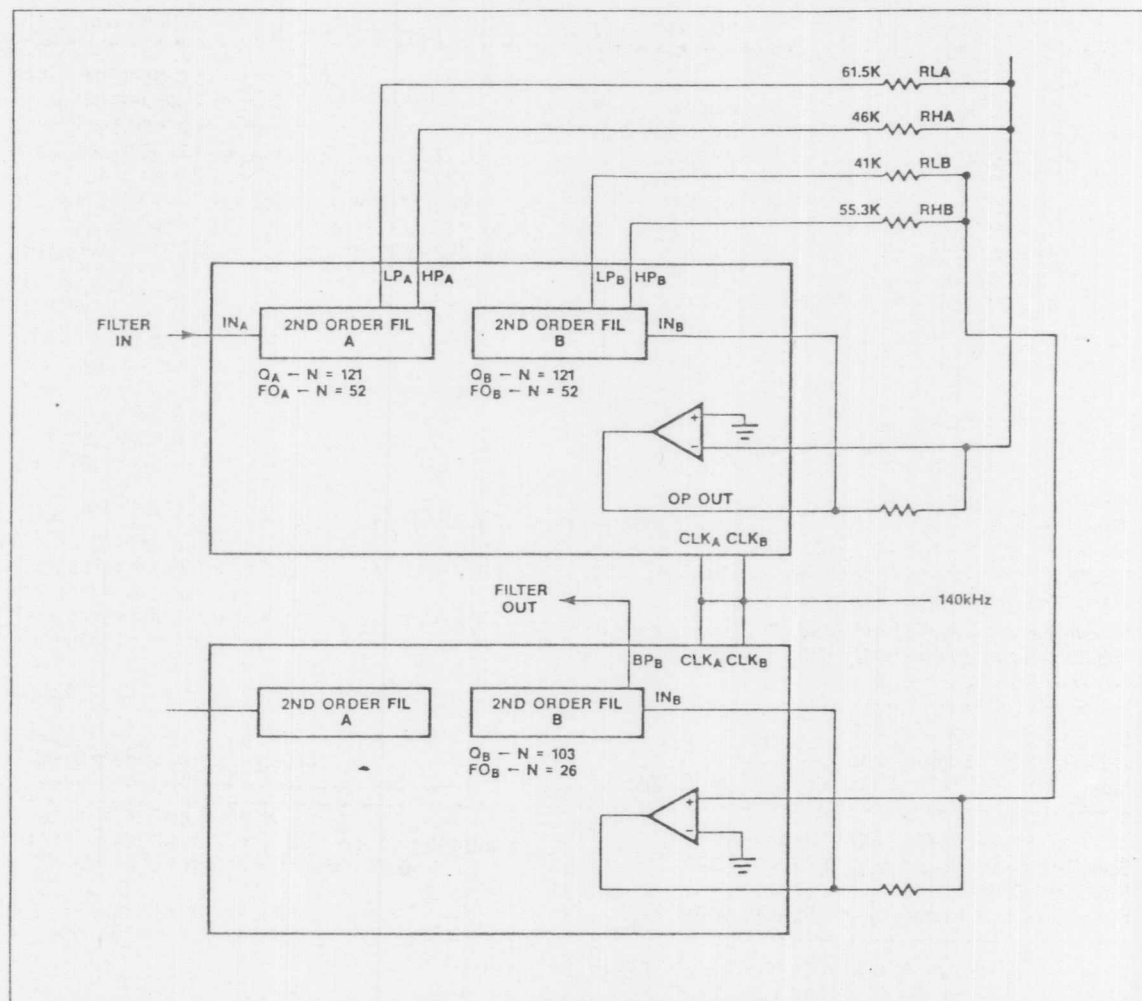


Figure 7. Design example #3 to implement 6th order elliptic bandpass filter with μP or pin programmed parts. Mode 3A is used.

Frequency of zero, $f_z = 665.3685$ Hertz Gain = 1.0000 V/V
 $H0_N = 1.0000$ total gain at $f = f_0$
 $H0_N_1 = 0.3253$ total gain at $f = \text{zero Hertz}$
 $H0_N_2 = 0.4348$ total gain at $f = \text{clkfreq}/2$
 $RG = 20.0000$, $RH = 46.0025$, $RL = 61.4910$ K ohm

DATA INPUT FOR SECTION #2

Specified center frequency, f_0 , is 1296.1851
 Specified Q is 9.1317
 Specified clock frequency is 140000.0000

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F0 CODE REQUIRED FOR SECTION #2

Code for clock ratio: N = 5 = 0 0 0 1 0 1

Q CODE REQUIRED FOR SECTION #2

Code for Q selection: N = 121 = 1 1 1 1 0 0 1

COMMENT ON SECTION #2

Above code applies to parts with a SIX BIT clock/center freq ratio code
(code for parts with ratio range of 100-200, except mode 2 with 71-142)

Value of center frequency 'targeted' was 1291.6923

Actual center frequency delivered by the circuit will be 1293.6506

Clock ratio dialed in is 108.3849

The Q 'targeted' was 9.1408

Value of Q delivered by the circuit is 9.1339

Following are gains at filter terminals:

H0__LP = -1.0, H0__HP = -1.0, H0__BP = -Q = -9.1339 (freq = f0)

Frequency of zero, fz = 1502.9266 Hertz Gain = 1.1560 V/V

H0__N = 1.1560 total gain at f = f0

H0__N__1 = 0.4881 total gain at f = zero Hertz

H0__N__2 = 0.3616 total gain at f = clk__freq/2

RG= 20.0000, RH= 55.3054, RL= 40.9757 K ohm

Keystroke input to second run of MPP: Elliptic BP third section/
/2/6/3/1/1000/2.6077/1/140000

Example 3

2/25/88 18.28 Elliptic BP third section

MPP<0 2>

Maxim Program MPP: Calculations for Mode 3

DATA INPUT

Specified center frequency, f0, is 1000.0000

Specified Q is 2.6077

Specified clock frequency is 140000.0000

F0 CODE REQUIRED

Code for clock ratio: N = 26 = 0 1 1 0 1 0

Q CODE REQUIRED

Code for Q selection: N = 103 = 1 1 0 0 1 1 1

COMMENT

Above code applies to parts with a SIX BIT clock/center freq ratio code
(code for parts with ratio range of 100-200, except mode 2 with 71-142)

Value of center frequency 'targeted' was 990.2974

Actual center frequency delivered by the circuit will be 996.8330

Clock ratio dialed in is 141.3717

The Q 'targeted' was 2.6131

Value of Q delivered by the circuit is 2.5547

Following are gains at filter terminals:

H0__LP = -1.0, H0__HP = -1.0, H0__BP = -Q = -2.5547 (freq = f0)

The frequency response of the three stages designed above will now be evaluated using FR.

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Keystroke input to FR: Elliptic BP, μ P programmed/
2/2/b/y/769.2678/9.143/20/46.0025/61.491/<ret>
/2/2/b/y/1293.6506/9.1339/20/55.3054/40.9757/<ret>
/2/2/b/n/996.833/2.5547/2.5547/e/1/0/2000/20/y/1000/n/n

Example 3

2/25/88 18:28 Elliptic BP, μ P programmed

FR<0.2>

(Section # 1) The order is 2
This is a Mode 3A section Gain set internally
Bandpass Pole frequency = 769.2678
Q = 9.1430
Zero (if not = 0) is 0.0000
RG = 20.0000 RH = 46.0025 RL = 61.4910
H0__LP = 1.0000 H0__HP = 1.0000
Section gain factor is 1.0000

(Section # 2) The order is 2
This is a Mode 3A section Gain set internally
Bandpass Pole frequency = 1293.6506
Q = 9.1339
Zero (if not = 0) is 0.0000
RG = 20.0000 RH = 55.3054 RL = 40.9757
H0__LP = 1.0000 H0__HP = 1.0000
Section gain factor is 1.0000

(Section # 3) The order is 2
Not an Mode 3A section Gain set internally
Bandpass Pole frequency = 996.8330
Q = 2.5547
Zero (if not = 0) is 0.0000
Section gain factor is 2.5547

(Note: the following information on quadratic coefficients of S is for information only and is not required for the design.)

Quadratic Coefficients for Denormalized Gain Function in Rad/Sec

Numerator			Denominator			Gain factor
s ²	s ¹	s ⁰	s ²	s ¹	s ⁰	
4.35E-01	0.00E+00	7.60E+06	1.00E+00	5.29E+02	2.34E+07	1.00E+00
3.62E-01	0.00E+00	3.22E+07	1.00E+00	8.90E+02	6.61E+07	1.00E+00
0.00E+00	2.45E+03	0.00E+00	1.00E+00	2.45E+03	3.92E+07	2.55E+00

Gain is normalized at 1000.0000, -0.1573 db

Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
0.000	*****	*****	*****
100.000	-35.758	86.412	1.01830E-04
200.000	-29.617	82.582	1.12343E-04
300.000	-25.934	78.202	1.33060E-04
400.000	-23.339	72.795	1.71283E-04
500.000	-21.738	65.435	2.47062E-04
600.000	-22.938	53.734	4.37177E-04
700.000	-18.654	26.683	1.36292E-03
800.000	0.034	-83.309	2.90984E-03
900.000	-0.387	-141.650	1.13844E-03

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Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
0.000	*****	*****	*****
1000.000	0.000	178.842	1.06289E-03
1100.000	-0.341	143.188	9.25928E-04
1200.000	-0.177	107.114	1.23976E-03
1300.000	-1.541	36.649	2.46839E-03
1400.000	-14.392	-20.910	8.41758E-04
1500.000	-51.423	-40.437	3.52939E-04
1600.000	-25.432	-50.016	2.02455E-04
1700.000	-22.727	-55.963	1.35445E-04
1800.000	-21.984	-60.121	9.87291E-05
1900.000	-21.856	-63.236	7.59795E-05
2000.000	-21.983	-65.680	6.07103E-05

The target gain was unity and in the normalizing offset above of -1573 dB or 0.982 V/V it can be seen that the objective was closely approximated. The difference is explained by the Q of the third stage which was targeted at 2.6077 but which actually came out at 2.5547.

Design example #4.

Specification:

Chebyshev notch, center frequency 1000 Hz, pass bandwidth 200 Hz, stop bandwidth 10 Hz, maximum ripple 1 dB, minimum attenuation 50 dB. Clock frequency 100,000 Hz. Gain = 1.

Steps in example:

- (1) analyze design with PZ
- (2) design two stages of resistor programmed filters in Mode 3A using RP
- (3) check design from RP using FR.
- (4) design two stages using μ P programmable filters in Mode 3A using MPP
- (5) check design from MPP using FR.

In PZ two frequency response runs are made, one wide and one narrower.

Keystroke input to PZ: Chebyshev notch/n/c/2/1/1000/200/n/50/10/n/y/
1/0/2000/20/y/0/n/y/1/900/1100/20/y/0/n/n

Example 4

2/26/88 9:41 Chebyshev notch

PZ<0.2>

FILTER TYPE: CHEBYSHEV NOTCH

Specified Parameters:

Center Frequency is 1000.0000 Pass Bandwidth is 200.0000
Stop Bandwidth is 10.0000
Amin=50.00 db Amax= 1.0000 db

Calculated Parameters:

Pass Band Low Edge is 904.9876 Pass Band High Edge is 1104.9876
Stop Band Low Edge is 995.0125 Stop Band High Edge is 1005.0125
Order= 4 N= 2 Actual Attenuation=52.18

Data for Lowpass Prototype, Normalized at 1 rad/sec:

FC=	1.0000FS=	20.0000
	Pole	Q
	1.0500	0.9565

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Data for final design of CHEBYSHEV NOTCH Filter

Quadratic Coefficients for Denormalized Gain Function in Rad/Sec

Numerator			Denominator		
s ²	s ¹	s ⁰	s ²	s ¹	s ⁰
1.0	0.000E+00	3.948E+07	1.0	5.749E+02	3.356E+07
1.0	0.000E+00	3.948E+07	1.0	6.763E+02	4.644E+07

Resonant Frequencies in Hertz:

Pole	Q
922.0084	10.0766
1084.5888	10.0766
Zero	
1000.0000	
1000.0000	

Example 4

2/26/88 9.41 Chebyshev notch

PZ<0.2>

Gain is normalized at 0.0000, -1.0000 db

Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
0.000	0.000	0.000	3.16931E-05
100.000	0.001	-1.153	3.26830E-05
200.000	0.006	-2.379	3.58722E-05
300.000	0.015	-3.771	4.20307E-05
400.000	0.032	-5.462	5.29231E-05
500.000	0.063	-7.685	7.26078E-05
600.000	0.123	-10.915	1.11704E-04
700.000	0.256	-16.350	2.05760E-04
800.000	0.607	-28.329	5.43828E-04
900.000	0.342	-78.848	3.11863E-03
1000.000	-443.625	180.	1.74710E-03
1100.000	-0.366	89.751	2.91285E-03
1200.000	0.819	36.642	6.12554E-04
1300.000	0.459	23.299	2.24645E-04
1400.000	0.287	17.468	1.17148E-04
1500.000	0.198	14.151	7.26082E-05
1600.000	0.146	11.988	4.97826E-05
1700.000	0.113	10.455	3.64662E-05
1800.000	0.091	9.306	2.79883E-05
1900.000	0.075	8.408	2.22399E-05
2000.000	0.063	7.685	1.81520E-05

Example 4

2/26/88 9.41 Chebyshev notch

PZ<0.2>

Gain is normalized at 0.0000, -1.0000 db

Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
900.000	0.342	-78.848	3.11863E-03
910.000	-0.459	-90.910	3.55740E-03
920.000	-1.800	-104.190	3.77170E-03
930.000	-3.796	-117.685	3.67454E-03
940.000	-6.486	-130.347	3.33116E-03
950.000	-9.886	-141.559	2.89430E-03
960.000	-14.092	-151.224	2.48685E-03
970.000	-19.428	-159.568	2.16456E-03
980.000	-26.763	-166.925	1.93857E-03
990.000	-39.021	-173.634	1.80247E-03

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Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
1000.000	-443.625	180.000	1.74710E-03
1010.000	-39.196	173.698	1.76605E-03
1020.000	-27.117	167.199	1.85660E-03
1030.000	-19.969	160.245	2.01811E-03
1040.000	-14.827	152.586	2.24768E-03
1050.000	-10.807	143.995	2.53197E-03
1060.000	-7.559	134.332	2.83528E-03
1070.000	-4.941	123.637	3.09118E-03
1080.000	-2.899	112.234	3.21582E-03
1090.000	-1.396	100.712	3.15238E-03
1100.000	-0.366	89.751	2.91285E-03

The two stages are now to be designed using RP. Since the Q is quite high the first stage is made with a lowpass gain of 0.2 and the gain of 1 is achieved by a gain of 5 in the op amp. In the second stage the lowpass gain is made unity, for an overall system gain of unity. We choose to set the gains on the high side of the notch in this example. This will fit with the simplification (explained below) where the op amp is eliminated and the first amplifier of the second stage takes its place. The resistor R2 of the second stage then acts in place of RG of the first stage.

Keystroke input for first run of RP: First section/2/6/3a/3/100000/102/
922.0084/10.0766/2/2/1000/2/1

Example 4

2/26/88 9:47 First section

Notch using Mode 3A

RP<0.2>

R1 =	100.0000	This group of resistors, expressed in K ohms, is scaled so that the smallest is 20.00K ohms. They may be rescaled to other reasonable values using a constant multiplying factor.
R2 =	20.0000	
R3 =	214.5861	
R4 =	22.6195	

Both clock ratio and clock frequency specified by user

RG =	104.0105	This group of resistors may be rescaled to other reasonable values using a constant multiplying factor.
RH =	20.8021	
RL =	20.0000	

H0__LP	= -0.2262	(intermediate node)
H0__HP =	-0.2000	(intermediate node)
H0__BP =	-2.1459	(intermediate node)
H0__N =	1.7790	= gain for F=F0, out of op amp
H0__N__1 =	1.1763	= gain as F tends to zero Hertz, out of op amp
H0__N__2 =	1.0000	= gain for F=F__CLK/2, out of op amp
F0 =	922.0084	Target value
F0 =	920.9591	Value after warp
F0 =	922.0084	Actual value achieved
FN =	1000.0000	
Q =	10.0766	Target value
Q =	10.0889	Value after warp
Q =	10.0766	Actual achieved value
clk ratio=	102.0000	Specified value
clk ratio=	102.1018	Actual quantized value
clkfreq=	100000.0000	
N=	1	0 0 0 0 1 are pin settings for clock ratio

(this code proper for parts with nominal ratio range of approx 100-200)

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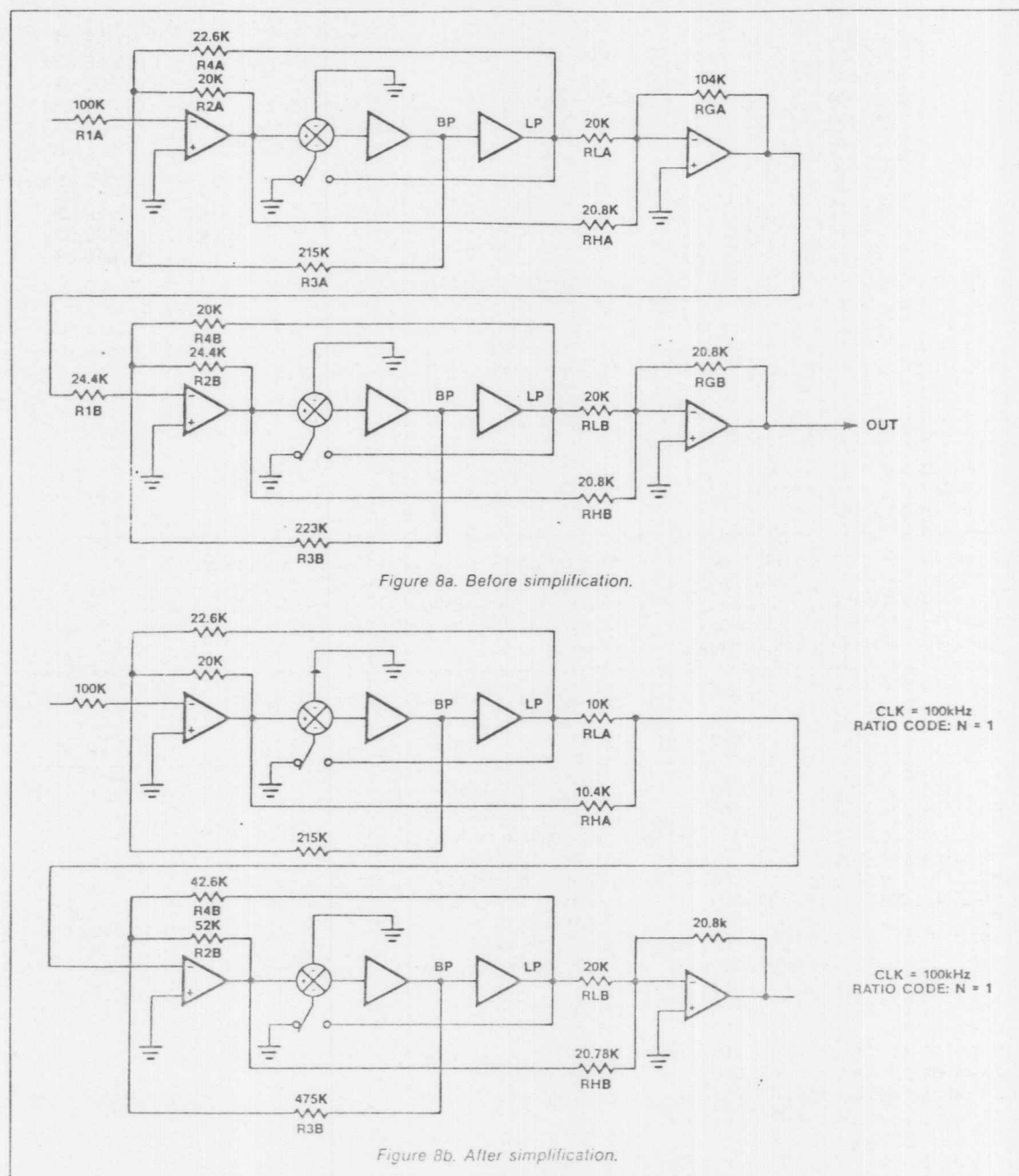


Figure 8. Design example #4 with resistor programming to implement 4th order notch filter.

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Keystroke input to second run of RP: Second section/2/6/3a/3/100000/102/
1084.5888/10.0766/2/1/1000/2/1

Example 4

2/26/88 9:50 Second section

RP<0.2>

Notch using Mode 3A

R1 =	24.4477	This group of resistors, expressed in K ohms, is scaled so that the smallest is 20.00K ohms. They may be rescaled to other reasonable values using a constant multiplying factor.
R2 =	24.4477	
R3 =	223.1592	
R4 =	20.0000	

Both clock ratio and clock frequency specified by user

RG =	20.7829	This group of resistors may be rescaled to to other reasonable values using a constant multiplying factor.
RH =	20.7829	
RL =	20.0000	

H0__LP =	-0.8181	(intermediate node)
H0__HP =	-1.0000	(intermediate node)
H0__BP =	-9.1280	(intermediate node)
H0__N =	1.5128	= gain for F=F0, out of op amp
H0__N__1 =	0.8501	= gain as F tends to zero Hertz, out of op amp
H0__N__2 =	1.0000	= gain for F=F__CLK/2, out of op amp
F0 =	1084.5888	Target value
F0 =	1082.8552	Value after warp
F0 =	1084.5888	Actual value achieved
FN =	1000.0000	
Q =	10.0766	Target value
Q =	10.0921	Value after warp
Q =	10.0766	Actual achieved value
clk ratio=	102.0000	Specified value
clk ratio=	102.1018	Actual quantized value
clkfreq=	100000.0000	
N=	1	0 0 0 0 1 are pin settings for clock ratio

(this code proper for parts with nominal ratio range of approx 100-200)

SIMPLIFICATION OF THE CIRCUIT

The above implementation of the zeros for the notch filters assumes the use of separate op amps. In practice the input amplifier of the second stage may serve the purpose of the op amp for the first zero with R2 of the second stage acting in the place of RG. To simplify the circuit some of the resistors need to change value though the ratios are preserved in the appropriate groups of resistors. Below are the resistor values before and after simplification.

	BEFORE	AFTER	SCALE FACTOR
R1A	100	100	1
R2A	20	20	1
R3A	215	215	1
R4A	22.6	22.6	1
RGA	104	R2B=52	0.5
RGA	20.8	10.4	0.5
RLA	20	10	0.5

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R1B	24.4	DELETE	
R2B	24.4	52	2.13
R3B	223	475	2.13
R4B	20	42.6	2.13
RGB	20.8	20.8	1
RGB	20.8	20.8	1
RLB	20	20	1

The results of the two RP runs are now checked using FR. Two frequency response runs are made to match those made in PZ.

Keystroke input to FR: Cheb notch, res programmed/2/1/n/y
/922.0084/10.0766/104.0105/20.8021/20/.2262/.2
/2/1/n/y/1084.5888/10.0766/20.7829/20.7829/20/.8181/1/e
/1/0/2000/20/y/0/n/y/1/900/1100/20/y/0/n/n

Example 4

2/26/88 9:52 Cheb notch, res programmed

FR<0.2>

(Section # 1) The order is 2

This is a Mode 3A section Gain set by resistors

Notch Pole frequency = 922.0084

Q = 10.0766

Zero (if not = 0) is 0.0000

RG = 104.0105 RH = 20.8021 RL = 20.0000

H0__LP = 0.2262 H0__HP = 0.2000

Section gain factor is 1.0000

(Section # 2) The order is 2

This is a Mode 3A section Gain set by resistors

Notch Pole frequency = 1084.5888

Q = 10.0766

Zero (if not = 0) is 0.0000

RG = 20.7829 RH = 20.7829 RL = 20.0000

H0__LP = 0.8181 H0__HP = 1.0000

Section gain factor is 1.0000

(Note: the following information on quadratic coefficients of S is for information only and is not required for the design.)

Quadratic Coefficients for Denormalized Gain Function in Rad/Sec

Numerator				Denominator		Gain factor
s^2	s^1	s^0	s^2	s^1	s^0	
1.00E+00	0.00E+00	3.95E+07	1.00E+00	5.75E+02	3.36E+07	1.00E+00
1.00E+00	0.00E+00	3.95E+07	1.00E+00	6.76E+02	4.64E+07	1.00E+00

Gain is normalized at 0.0000, 0.0004 db

Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
0.000	0.000	0.000	3.16932E-05
100.000	0.001	-1.153	3.26831E-05
200.000	0.006	-2.379	3.58724E-05
300.000	0.016	-3.771	4.20309E-05
400.000	0.032	-5.462	5.29233E-05
500.000	0.063	-7.685	7.26081E-05
600.000	0.123	-10.915	1.11704E-04
700.000	0.257	-16.350	2.05761E-04
800.000	0.608	-28.330	5.43830E-04
900.000	0.344	-78.849	3.11862E-03

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Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
1000.000	-154.982	180.000	1.74710E-03
1100.000	-0.369	89.751	2.91284E-03
1200.000	0.818	36.643	6.12555E-04
1300.000	0.458	23.299	2.24646E-04
1400.000	0.286	17.468	1.17148E-04
1500.000	0.198	14.151	7.26084E-05
1600.000	0.146	11.988	4.97828E-05
1700.000	0.113	10.455	3.64663E-05
1800.000	0.090	9.306	2.79884E-05
1900.000	0.074	8.408	2.22400E-05
2000.000	0.062	7.685	1.81520E-05

Example 4

2/26/88 9:52 Cheb notch, res programmed

FR<0.2>

(Section # 1) The order is 2

This is a Mode 3A section Gain set by resistors

Notch Pole frequency = 922.0084

Q = 10.0766

Zero (if not = 0) is 0.0000

RG = 104.0105 RH = 20.8021 RL = 20.0000

H0__LP = 0.2262 H0__HP = 0.2000

Section gain factor is 1.0000

(Section # 2) The order is 2

This is a Mode 3A section Gain set by resistors

Notch Pole frequency = 1084.5888

Q = 10.0765

Zero (if not = 0) is 0.0000

RG = 20.7373 RH = 20.7829 RL = 20.0000

H0__LP = 0.8181 H0__HP = 1.0000

Section gain factor is 1.0000

(Note: the following information on quadratic coefficients of S is for information only and is not required for the design.)

Quadratic Coefficients for Denormalized Gain Function in Rad/Sec

Numerator		Denominator				Gain factor
s^2	s^1	s^2	s^1	s^0	s^0	
1.00E+00	0.00E+00	3.95E+07	1.00E+00	5.75E+02	3.36E+07	1.00E+00
1.00E+00	0.00E+00	3.95E+07	1.00E+00	6.76E+02	4.64E+07	1.00E+00

Gain is normalized at 0.0000, 0.0004 db

Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
900.000	0.344	-78.849	3.11862E-03
910.000	-0.457	-90.910	3.55739E-03
920.000	-1.798	-104.190	3.77169E-03
930.000	-3.793	-117.685	3.67453E-03
940.000	-6.482	-130.347	3.33115E-03
950.000	-9.881	-141.559	2.89429E-03
960.000	-14.087	-151.224	2.48685E-03
970.000	-19.421	-159.568	2.16456E-03
980.000	-26.752	-166.925	1.93857E-03
990.000	-38.999	-173.634	1.80248E-03
1000.000	-154.982	180.000	1.74710E-03

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Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
1010.000	-39.219	173.698	1.76605E-03
1020.000	-27.129	167.199	1.85660E-03
1030.000	-19.977	160.245	2.01811E-03
1040.000	-14.833	152.586	2.24768E-03
1050.000	-10.812	143.995	2.53197E-03
1060.000	-7.563	134.332	2.83527E-03
1070.000	-4.944	123.637	3.09117E-03
1080.000	-2.903	112.234	3.21581E-03
1090.000	-1.399	100.712	3.15237E-03
1100.000	-0.369	89.751	2.91284E-03

The same design is now done using μ P programmed parts with the help of MPP in mode 3A. In this case the lowpass and highpass gains are both fixed internally at unity and the op amps are used to form the notches. The gain is set in all cases at zero Hertz.

Keystroke input to MPP: Cheb notch, μ P programmed/2/6/3a/2/
922.0084/10.0766/1000/1/1/1084.5888/10.0766/1000/1/1/120000/120000

Example 4

2/26/88 10:03 Cheb notch, μ P programmed
Maxim Program MPP: Calculations for Mode 3A

MPP<0.2>

DATA INPUT FOR SECTION #1

Specified center frequency, f_0 , is 922.0084
Specified Q is 10.0766
Specified clock frequency is 120000.0000

F0 CODE REQUIRED FOR SECTION #1

Code for clock ratio: N = 19 = 0 1 0 0 1 1

Q CODE REQUIRED FOR SECTION #1

Code for Q selection: N = 122 = 1 1 1 1 0 1 0

COMMENT ON SECTION #1

Above code applies to parts with a SIX BIT clock/center freq ratio code
(code for parts with ratio range of 100-200, except mode 2 with 71-142)

Value of center frequency 'targeted' was 920.4141

Actual center frequency delivered by the circuit will be 921.4431

Clock ratio dialed in is 130.3761

The Q 'targeted' was 10.0766

Value of Q delivered by the circuit is 10.6670

Following are gains at filter terminals:

H0__LP = -1.0, H0__HP = -1.0, H0__BP = -Q = -10.6670 (freq = f_0)

Frequency of zero, f_z = 1000.0000 Hertz Gain = 1.0000 V/V

H0__N = 1.5210 total gain at $f = f_0$

H0__N__1 = 1.0000 total gain at $f =$ zero Hertz

H0__N__2 = 0.8491 total gain at $f = \text{clk_freq}/2$

RG= 20.0000, RH= 23.5555, RL= 20.0000 K ohm

DATA INPUT FOR SECTION #2

Specified center frequency, f_0 , is 1084.5888
Specified Q is 10.0766
Specified clock frequency is 120000.0000

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F0 CODE REQUIRED FOR SECTION #2
Code for clock ratio: N = 7 = 0 0 0 1 1 1

Q CODE REQUIRED FOR SECTION #2
Code for Q selection: N = 122 = 1 1 1 1 0 1 0

COMMENT ON SECTION #2
Above code applies to parts with a SIX BIT clock/center freq ratio code
(code for parts with ratio range of 100-200, except mode 2 with 71-142)
Value of center frequency 'targeted' was 1075.9771
Actual center frequency delivered by the circuit will be 1077.2883
Clock ratio dialed in is 111.5265
The Q 'targeted' was 10.0830
Value of Q delivered by the circuit is 10.6602
Following are gains at filter terminals:
H0__LP = -1.0, H0__HP = -1.0, H0__BP = -Q = -10.6602 (freq = f0)

Frequency of zero, fz = 1000.0000 Hertz Gain = 1.0000 V/V
H0__N = 1.6188 total gain at f = f0
H0__N__1 = 1.0000 total gain at f = zero Hertz
H0__N__2 = 1.1606 total gain at f = clk__freq/2
RG = 23.2110, RH = 20.0000, RL = 23.2110 K ohm

The design from MPP is now checked with FR.
Keystroke input to FR: Cheb notch, μ P programmed
/2/2/n/y/921.4431/10.667/20/23.5555/20/<return>
/2/2/n/y/1077.2883/10.6602/23.211/20/23.211/<return>/e
/1/0/2000/20/y/0/n/y/1/900/1100/20/y/0/n/n

Example 4
2/26/88 10:03 Cheb notch, μ P programmed

FR<0.2>

(Section # 1) The order is 2
This is a Mode 3A section Gain set internally
Notch Pole frequency = 921.4431
Q = 10.6670
Zero (if not = 0) is 0.0000
RG = 20.0000 RH = 23.5555 RL = 20.0000
H0__LP = 1.0000 H0__HP = 1.0000
Section gain factor is 1.0000

(Section # 2) The order is 2
This is a Mode 3A section Gain set internally
Notch Pole frequency = 1077.2883
Q = 10.6602
Zero (if not = 0) is 0.0000
RG = 23.2110 RH = 20.0000 RL = 23.2110
H0__LP = 1.0000 H0__HP = 1.0000
Section gain factor is 1.0000

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(Note: the following information on quadratic coefficients of S is for information only and is not required for the design.)

Quadratic Coefficients for Denormalized Gain Function in Rad/Sec

Numerator			Denominator			Gain factor
s ²	s ¹	s ⁰	s ²	s ¹	s ⁰	
8.49E-01	0.00E+00	3.35E+07	1.00E+00	5.43E+02	3.35E+07	1.00E+00
1.16E+00	0.00E+00	4.58E+07	1.00E+00	6.35E+02	4.58E+07	1.00E+00

Gain is normalized at 0.0000, 0.0000 db

Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
0.000	0.000	0.000	3.00510E-05
100.000	0.003	-1.093	3.09952E-05
200.000	0.011	-2.257	3.40378E-05
300.000	0.028	-3.577	3.99170E-05
400.000	0.055	-5.184	5.03262E-05
500.000	0.103	-7.300	6.91661E-05
600.000	0.191	-10.381	1.06669E-04
700.000	0.373	-15.581	1.97249E-04
800.000	0.836	-27.120	5.26625E-04
900.000	1.053	-77.871	3.25487E-03
1000.000	-230.440	177.594	1.80606E-03
1100.000	-0.382	80.767	2.77895E-03
1200.000	0.372	33.408	5.38153E-04
1300.000	0.118	21.542	2.02566E-04
1400.000	0.008	16.248	1.07070E-04
1500.000	-0.044	13.206	6.68633E-05
1600.000	-0.073	11.209	4.60591E-05
1700.000	-0.089	9.788	3.38459E-05
1800.000	-0.100	8.720	2.60364E-05
1900.000	-0.107	7.884	2.07242E-05
2000.000	-0.112	7.210	1.69373E-05

Example 4

2/26/88 10:03 Cheb notch, μ P programmed

FR<0.2>

(Section # 1) The order is 2

This is a Mode 3A section Gain set internally

Notch Pole frequency = 921.4431

Q = 10.6670

Zero (if not = 0) is 0.0000

RG = 20.0000 RH = 23.5555 RL = 20.0000

H0__LP = 1.0000 H0__HP = 1.0000

Section gain factor is 1.0000

(Section # 2) The order is 2

This is a Mode 3A section Gain set internally

Notch Pole frequency = 1077.2883

Q = 10.6602

Zero (if not = 0) is 0.0000

RG = 23.2110 RH = 20.0000 RL = 23.2110

H0__LP = 1.0000 H0__HP = 1.0000

Section gain factor is 1.0000

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(Note: the following information on quadratic coefficients of S is for information only and is not required for the design.)

Quadratic Coefficients for Denormalized Gain Function in Rad/Sec

Numerator			Denominator			Gain factor
s ²	s ¹	s ⁰	s ²	s ¹	s ⁰	
8.49E-01	0.00E+00	3.35E+07	1.00E+00	5.43E+02	3.35E+07	1.00E+00
1.16E+00	0.00E+00	4.58E+07	1.00E+00	6.35E+02	4.58E+07	1.00E+00

Gain is normalized at 0.0000, 0.0000 db

Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
900.000	1.053	-77.871	3.25487E-03
910.000	0.321	-90.534	3.75271E-03
920.000	-0.989	-104.571	3.98728E-03
930.000	-2.999	-118.791	3.85295E-03
940.000	-5.734	-131.977	3.44276E-03
950.000	-9.183	-143.481	2.94861E-03
960.000	-13.426	-153.276	2.50885E-03
970.000	-18.779	-161.675	2.17638E-03
980.000	-26.113	-169.080	1.95564E-03
990.000	-38.355	-175.877	1.83579E-03
1000.000	-230.440	177.594	1.80606E-03
1010.000	-38.458	171.019	1.86054E-03
1020.000	-26.334	164.099	1.99791E-03
1030.000	-19.142	156.534	2.21806E-03
1040.000	-13.970	148.037	2.51415E-03
1050.000	-9.952	138.373	2.85835E-03
1060.000	-6.763	127.476	3.18496E-03
1070.000	-4.280	115.586	3.39162E-03
1080.000	-2.445	103.314	3.38616E-03
1090.000	-1.183	91.479	3.15620E-03
1100.000	-0.382	80.767	2.77895E-03

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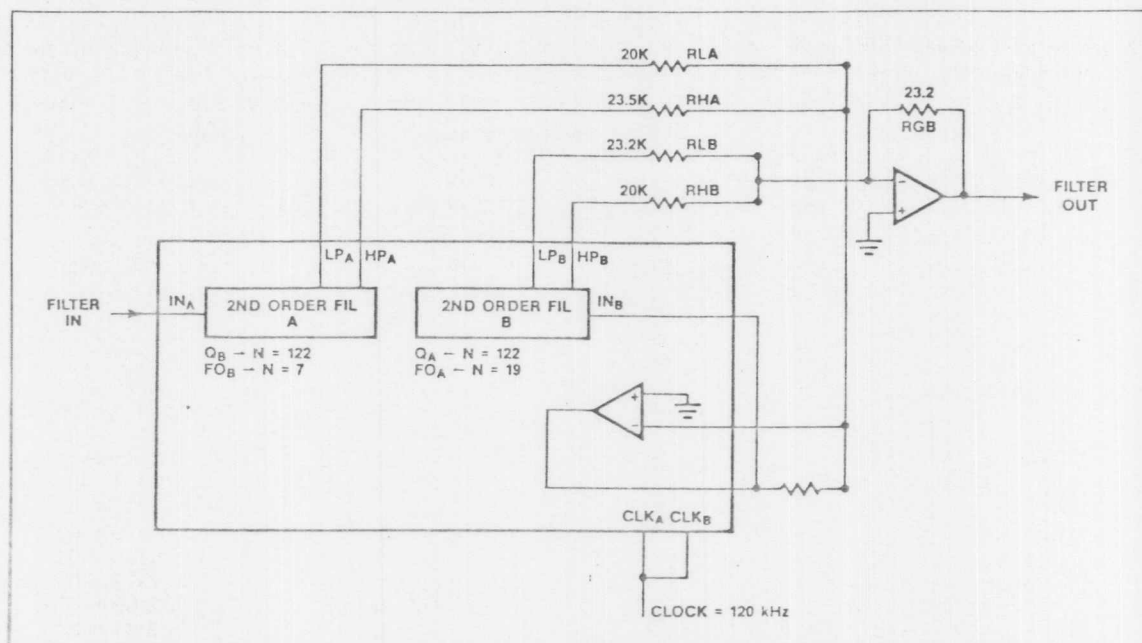


Figure 9. Design Example #4 to implement 4th order Notch Filter with μP or pin programmed parts.

Design example #5.

Specifications:

Butterworth lowpass, $f_0=1000\text{Hz}$, stop freq = 2500 Hz, max ripple = 1 db, min attenuation = 24 dB, gain = 1V/V

Steps in example:

- (1) analyse system using PZ and get frequency response
- (2) design system for resistor programmed parts using RP
- (3) check frequency response of resistor design with FR
- (4) design system with μP programmed parts using MPP
- (5) check frequency response of this design with FR

Keystroke input to PZ: Butterworth lowpass/L/b/1/1000/n/24/2500/
n/y/1/0/3000/30/n

Example 5

2/26/88 10:16 Butterworth lowpass

PZ<0.2>

FILTER TYPE: BUTTERWORTH LOWPASS

Specified Parameters:

Corner Freq= 1000.0000 Stop Freq= 2500.0000
Amax= 1.0000 db Amin= 24.00 db

Calculated Parameters:

Order, N= 4 Actual Attenuation= 25.98 db

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Data for Lowpass Prototype, Normalized at 1 rad/sec:

FC=	1.0000FS=	2.5000
	Pole	Q
	1.1833	0.5412
	1.1833	1.3066

Data for final design of BUTTERWORTH LOWPASS Filter

Quadratic Coefficients for Denormalized Gain Function in Rad/Sec

Numerator			Denominator		
s^2	s^1	s^0	s^2	s^1	s^0
0.0	0.000E+00	5.528E+07	1.0	1.374E+04	5.528E+07
0.0	0.000E+00	5.528E+07	1.0	5.690E+03	5.528E+07

Resonant Frequencies in Hertz:

Pole	Q
1183.3014	0.5412
1183.3014	1.3066

Example 5

2/26/88 10:16 Butterworth lowpass

PZ<0.2>

Gain not normalized

Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
0.000	0.004	0.000	3.51467E-04
100.000	0.004	-12.665	3.52515E-04
200.000	0.004	-25.407	3.55753E-04
300.000	0.004	-38.310	3.61514E-04
400.000	0.004	-51.474	3.70465E-04
500.000	-0.000	-65.035	3.83712E-04
600.000	-0.015	-79.171	4.02735E-04
700.000	-0.060	-94.117	4.28873E-04
800.000	-0.181	-110.133	4.61830E-04
900.000	-0.457	-127.397	4.96808E-04
1000.000	-1.000	-145.787	5.21939E-04
1100.000	-1.921	-164.669	5.21808E-04
1200.000	-3.256	-177.034	4.89684E-04
1300.000	-4.940	-160.350	4.34708E-04
1400.000	-6.844	-145.815	3.72883E-04
1500.000	-8.842	-133.446	3.15572E-04
1600.000	-10.850	-122.985	2.67155E-04
1700.000	-12.817	-114.101	2.27830E-04
1800.000	-14.719	-106.488	1.96245E-04
1900.000	-16.546	-99.898	1.70808E-04
2000.000	-18.295	-94.133	1.50138E-04
2100.000	-19.970	-89.044	1.33148E-04
2200.000	-21.572	-84.512	1.19016E-04
2300.000	-23.108	-80.448	1.07128E-04
2400.000	-24.580	-76.778	9.70212E-05
2500.000	-25.994	-73.445	8.83467E-05
2600.000	-27.354	-70.403	8.08374E-05
2700.000	-28.663	-67.613	7.42865E-05
2800.000	-29.925	-65.045	6.85320E-05
2900.000	-31.143	-62.671	6.34454E-05
3000.000	-32.320	-60.470	5.89240E-05

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A design for resistor programmed parts will now be done with the aid of RP. The clock frequency used is 120000 Hz and for the first stage the program will select the clock frequency. For the second stage both the clock frequency and the clock ratio will be defined by the user so that both stages may have the same clock frequency and clock ratio.

Keystroke input to first run of RP: Res programmed, first section
/2/2/1/1/120000/1183.3014/.5412/1

Example 5

2/26/88 10:19 Res programmed, first section
Lowpass second order using Mode 1

RP<0.2>

R1 =	36.3453	This group of resistors, expressed in K ohms, is scaled so that the smallest is 20.00K ohms. They may be rescaled to other reasonable values using a constant multiplying factor.
R2 =	36.3453	
R3 =	20.0000	
R4 =	0.0000	

H0__N =	-1.0000	as f goes to 0, as f goes to F__clk/2
H0__LP =	-1.0000	
H0__BP =	-0.5503	
F__0=	1183.3014	Target value
F0=	1126.3159	Value after warp
F0=	1180.2870	Actual achieved value
FN=	1183.3014	Target value
FN=	1180.2870	Actual achieved value
Q =	0.5412	Target value
Q =	0.5503	Warped Q value
Q =	0.5412	Actual achieved value
clk ratio=	106.8142	
clk freq=	120000.0000	
N=	4	Ac

(this code proper for parts with nominal ratio range of approx 100-200)
Clock frequency specified by user, clock ratio calculated

Keystroke input to second run of RP: Res programmed, second section
/2/2/1/3/120000/106.8/1.3066/1

Example 5

2/26/88 10:21 Res programmed, second section
Lowpass second order using Mode 1

RP<0.2>

R1 =	20.0000	This group of resistors, expressed in K ohms, is scaled so that the smallest is 20.00K ohms. They may be rescaled to other reasonable values using a constant multiplying factor.
R2 =	20.0000	
R3 =	26.3330	
R4 =	0.0000	

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```

H0__N =          -1.0000      as f goes to 0, as f goes to F__clk/2
H0__LP =         -1.0000
H0__BP =         -1.3167
F0=            1145.3342      Actual achieved value
FN=            1145.3342      Actual achieved value
Q =             1.3066      Target value
Q =             1.3167      Warped Q value
Q =             1.3066      Actual achieved value
clk ratio=       106.8000      Value specified
clk ratio=       106.8142      Quantized value actually used
clk freq=       120000.0000    Specified value used
N=               4           0 0 0 1 0 0 are pin settings for clock ratio
                             (this code proper for parts with nominal ratio range of approx 100-200)
Both clock frequency and clock ratio specified

```

The two stages designed by RP will now have their frequency response checked using FR.

Keystroke input to FR: Res programmed/2/1/L/n/
1183.3014/.5412/1/2/1/L/n/1145.3342/1.3066/1/e/1/0/3000/30/n/n

Example 5

2/26/88 10:22 Res programmed

FR<0.2>

(Section # 1) The order is 2

Not an Mode 3A section Gain set by resistors

Lowpass Pole frequency =

1183.3014

Q = 0.5412

Zero (if not = 0) is

0.0000

Section gain factor is 1.0000

(Section #2) The order is 2

Not an Mode 3A section Gain setby resistors

Lowpass Pole frequency = 1145.3342

Q = 1.3066

Zero (if not = 0) is

0.0000

Section gain factor is

1.0000

(Note: the following information on quadratic coefficients of S is for information only and is not required for the design.

Quadratic Coefficients for Denormalized Gain Function in Rad/Sec

Numerator			Denominator			Gain factor
s^2	s^1	s^0	s^2	s^1	s^0	
0.00E+00	0.00E+00	5.53E+07	1.00E+00	1.37E+04	5.53E+07	1.00E+00
0.00E+00	0.00E+00	5.18E+07	1.00E+00	5.51E+03	5.18E+07	1.00E+00

Gain not normalized

Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
0.000	0.000	0.000	3.54875E-04
100.000	0.003	-12.790	3.56107E-04
200.000	0.012	-25.671	3.59927E-04
300.000	0.026	-38.741	3.66752E-04
400.000	0.046	-52.122	3.77398E-04
500.000	0.066	-65.975	3.93176E-04
600.000	0.077	-80.513	4.15756E-04
700.000	0.050	-96.007	4.46414E-04

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Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
800.000	-0.072	-112.739	4.83915E-04
900.000	-0.389	-130.846	5.20847E-04
1000.000	-1.030	-150.047	5.41650E-04
1100.000	-2.100	-169.452	5.30282E-04
1200.000	-3.602	172.182	4.85423E-04
1300.000	-5.426	155.818	4.22229E-04
1400.000	-7.426	141.793	3.57724E-04
1500.000	-9.483	129.964	3.01114E-04
1600.000	-11.521	119.990	2.54687E-04
1700.000	-13.501	111.515	2.17524E-04
1800.000	-15.407	104.238	1.87852E-04
1900.000	-17.232	97.920	1.63982E-04
2000.000	-18.977	92.378	1.44555E-04
2100.000	-20.646	87.471	1.28543E-04
2200.000	-22.242	83.091	1.15181E-04
2300.000	-23.771	79.153	1.03902E-04
2400.000	-25.238	75.591	9.42806E-05
2500.000	-26.646	72.349	8.59970E-05
2600.000	-28.001	69.386	7.88053E-05
2700.000	-29.305	66.664	7.25149E-05
2800.000	-30.563	64.156	6.69760E-05
2900.000	-31.776	61.835	6.20694E-05
3000.000	-32.950	59.680	5.76995E-05

The same design will now be made on μP programmed parts. Both stages are done in one run of MPP.
Keystroke input to MPP: μP programmed/2/6/1/2/1183.3014/.5412/
1183.3014/1.3066/1/120000/120000/n

Example 5

2/26/88 10:33 μP programmed
Maxim Program MPP: Calculations for Mode 1

MPP<0.2>

DATA INPUT FOR SECTION #1

Specified center frequency, f_0 , is 1183.3014
Specified Q is 0.5412
Specified clock frequency is 120000.0000

F0 CODE REQUIRED FOR SECTION #1

Code for clock ratio: N = 4 = 0 0 0 1 0 0

Q CODE REQUIRED FOR SECTION #1

Code for Q selection: N = 12 = 0 0 0 1 1 0 0

COMMENT ON SECTION #1

Above code applies to parts with a SIX BIT clock/center freq ratio code
(code for parts with ratio range of 100-200, except mode 2 with 71-142)
Value of center frequency 'targeted' was 1123.4467
Actual center frequency delivered by the circuit will be 1180.2872
Clock ratio dialed in is 106.8142
The Q 'targeted' was 0.5503
Value of Q delivered by the circuit is 0.5429
Following are gains at filter terminals:
H0__LP = -1.0, H0__N1 = -1.0 (freq = 0 Hz), H0__N2 = -1.0 (freq = clk/2)
H0__BP = -Q = -0.5429

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DATA INPUT FOR SECTION #2

Specified center frequency, f_0 , is 1183.3014
Specified Q is 1.3066
Specified clock frequency is 120000.0000

F0 CODE REQUIRED FOR SECTION #2

Code for clock ratio: $N = 2 = 000010$

Q CODE REQUIRED FOR SECTION #2

Code for Q selection: $N = 79 = 1001111$

COMMENT ON SECTION #2

Above code applies to parts with a SIX BIT clock/center freq ratio code
(code for parts with ratio range of 100-200, except mode 2 with 71-142)

Value of center frequency 'targeted' was 1157.4905

Actual center frequency delivered by the circuit will be 1180.6876

Clock ratio dialed in is 103.6726

The Q 'targeted' was 1.3171

Value of Q delivered by the circuit is 1.2956

Following are gains at filter terminals:

$H0_LP = -1.0$, $H0_N1 = -1.0$ (freq = 0 Hz), $H0_N2 = -1.0$ (freq = clk/2)

$H0_BP = -Q = -1.2956$

Keystroke input to FR: μP programmed/2/2/L/n/1180.2872/.5429/1

/2/2/L/n/1180.6876/1.2956/1/e/1/0/3000/30/n/n/n

Example 5

2/26/88 10:33 μP programmed

FR<0.2>

(Section # 1) The order is 2

Not an Mode 3A section Gain set internally

Lowpass Pole frequency = 1180.2872

Q = 0.5429

Zero (if not = 0) is 0.0000

Section gain factor is 1.0000

(Section # 2) The order is 2

Not an Mode 3A section Gain set internally

Lowpass Pole frequency = 1180.6876

Q = 1.2956

Zero (if not = 0) is 0.0000

Section gain factor is 1.0000

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(Note: the following information on quadratic coefficients of S is for information only and is not required for the design.)

Quadratic Coefficients for Denormalized Gain Function in Rad/Sec

Numerator			Denominator			Gain factor
s ²	s ¹	s ⁰	s ²	s ¹	s ⁰	
0.00E+00	0.00E+00	5.50E+07	1.00E+00	1.37E+04	5.50E+07	1.00E+00
0.00E+00	0.00E+00	5.50E+07	1.00E+00	5.73E+03	5.50E+07	1.00E+00

Gain not normalized

Freq (Hz)	Ampl (db)	Phase (deg)	Delay (sec)
0.000	0.000	0.000	3.52421E-04
100.000	0.000	-12.700	3.53522E-04
200.000	0.001	-25.481	3.56916E-04
300.000	0.002	-38.429	3.62917E-04
400.000	0.002	-51.650	3.72166E-04
500.000	-0.002	-65.277	3.85728E-04
600.000	-0.019	-79.491	4.05021E-04
700.000	-0.071	-94.523	4.31280E-04
800.000	-0.203	-110.623	4.64018E-04
900.000	-0.494	-127.952	4.98199E-04
1000.000	-1.058	-146.369	5.21896E-04
1100.000	-1.999	-165.220	5.20170E-04
1200.000	-3.350	176.562	4.87089E-04
1300.000	-5.042	159.975	4.32074E-04
1400.000	-6.947	145.526	3.70756E-04
1500.000	-8.944	133.223	3.14056E-04
1600.000	-10.949	122.807	2.66143E-04
1700.000	-12.912	113.952	2.27174E-04
1800.000	-14.811	106.359	1.95825E-04
1900.000	-16.636	99.780	1.70539E-04
2000.000	-18.384	94.024	1.49964E-04
2100.000	-20.056	88.939	1.33033E-04
2200.000	-21.658	84.411	1.18937E-04
2300.000	-23.192	80.349	1.07071E-04
2400.000	-24.664	76.681	9.69772E-05
2500.000	-26.078	73.350	8.83102E-05
2600.000	-27.437	70.309	8.08049E-05
2700.000	-28.746	67.520	7.42560E-05
2800.000	-30.008	64.953	6.85022E-05
2900.000	-31.226	62.580	6.34157E-05
3000.000	-32.403	60.380	5.88940E-05

NOTE ON ORDER OF STAGES IN CIRCUIT IMPLEMENTATION

The order in which the stages are placed does not affect the frequency response. However when large signals are expected and clipping may be a problem then the low Q section should be placed first as in these examples. If noise is of primary concern however it is better to place the high Q section first.

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UM-2

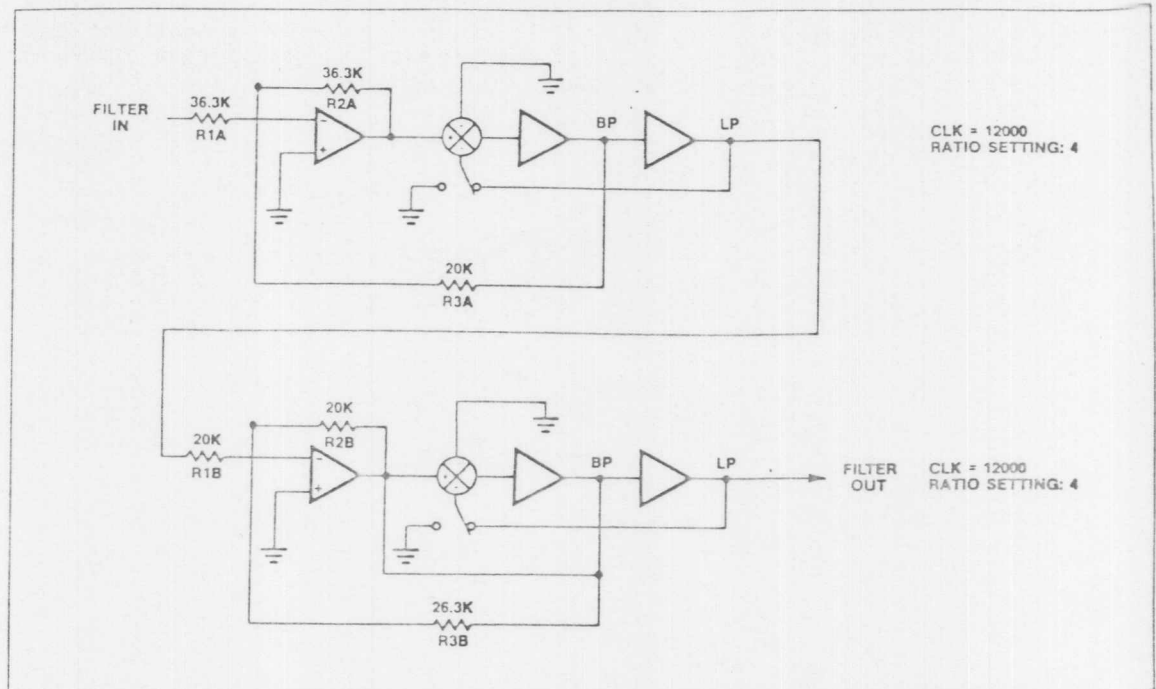


Figure 10. Design example 5 for resistor programming using mode 1 to implement Butterworth lowpass filter.

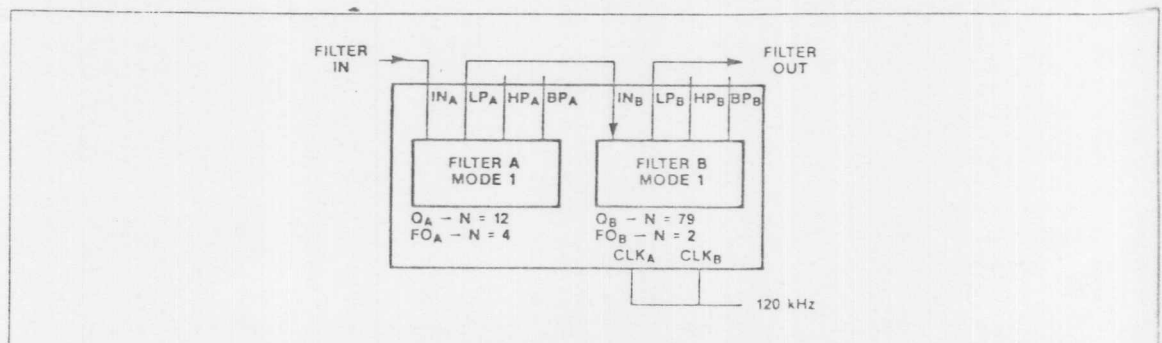


Figure 11. Design example 5 using μP programming, mode 1 to implement 4th order Butterworth lowpass filter.